U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-266 450

Open Space as an Air Resource Management Measure. Volume III: Demonstration Plan (St. Louis, Mo.)

COMSIS Corp, Glastonbury, Conn

Prepared for

Environmental Protection Agency, Research Triangle Park, N C Office of Air Quality Planning and Standards

Jan 77

PB 266 450

EPA-450/3-76-028c
November 1976

OPEN SPACE AS AN AIR RESOURCE MANAGEMENT MEASURE
VOLUME III: DEMONSTRATION PLAN (ST. LOUIS, MO.)

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-450/3-76-028c

OPEN SPACE AS AN AIR RESOURCE MANAGEMENT MEASURE

VOLUME III: DEMONSTRATION PLAN

(ST. LOUIS, MO.)

by

R.S. DeSanto, K.A. MacGregor,
W.P. McMillen, and R.A. Glaser

COMSIS Corporation
972 New London Turnpike
Glastonbury, Connecticut 06033

Contract No. 68-02-2350

EPA Project Officer: Thomas McCurdy

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

November 1976

i (a)

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - in limited quantities - from the Library Services Office (MD35), Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

This report was furnished to the Environmental Protection Agency by COMSIS Corporation, Glastonbury, Connecticut 06033, in fulfillment of Contract No. 68-02-2350. The contents of this report are reproduced herein as received from COMSIS Corporation. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

Publication No. EPA-450/3-76-028c

ACKNOWLEDGEMENTS

We wish to thank Mr. Thomas McCurdy, the EPA Project Officer for this study, whose assistance and advice was most valuable and greatly appreciated.

STAFFING

Dr. Robert S. DeSanto was Project Manager and principal investigator of this study at COMSIS CORPORATION - Environmental Services. Mr. William P. McMillen and Mr. Kenneth A. MacGregor,of COMSIS CORPORATION, assisted in all aspects of the study, providing engineering and planning overviews and writing much of the text. They were assisted by Miss Dana Pumphrey and Mr. Timothy Wagner, at all levels in preparation of the report. Their participation is greatly acknowledged. Mr. Richard A. Glaser, of David A. Crane & Partners, provided all of the landscape architectual imput including interpretations from the literature, illustrative material, and associated participation in the preparation of the final report. Mr. Mark Cooper, of David A. Crane & Partners assisted in the preparation of materials and his valuable help is greatfully acknowledged.

Mrs. Joy Maxfield typed the manuscript entirely alone. Her accuracy and stamina were very important to us and to our successful completion of this Volume. We are greatful to her for her support.

TABLE OF CONTENTS

Chapter	Title	Page
	LIST OF FIGURES	viii
	LIST OF TABLES	x
I	INTRODUCTION, APPROACH AND SUMMARY OF RESULTS	I-1
	A. INTRODUCTION AND ORGANIZATION OF REPORT	I-1
	B. SUMMARY OF THE RESULTS	I-2
II	ST. LOUIS CASE STUDY AREA	II-1
	A. SELECTION OF CASE STUDY AREA	II-1
	B. AIR QUALITY SYNOPSIS FOR ST. LOUIS	II-2
	C. AIR QUALITY MAINTENANCE ANALYSIS	II-6
	1. Existing Air Quality (1972)	II-6
	2. Emissions Projections	II-7
	3. Air Quality Projections	II-9
	4. Summary and Conclusions of the AQMA Analysis	II-18
III	AIR QUALITY MAINTENANCE PLAN AND RECENT DEVELOPMENTS IN ST. LOUIS	III-1
	A. AIR QUALITY MAINTENANCE PLAN	III-1
	1. Attainment Plans	III-1
	2. Recommended Attainment/Maintenance Strategies	III-4
	B. DEVELOPMENTS IN ST. LOUIS SINCE THE SUBMISSION OF THE AQMA PLAN	III-9
	1. Transportation Control Strategies	III-9
	2. Inspection/Maintenance	III-15
	3. Vapor Recovery	III-16
	4. SIP Regulations	III-16
	C. SUMMARY OF AIR CONTROL STRATEGIES IN ST. LOUIS	III-18
IV.	ANALYSIS OF OPEN SPACE AS A CONTROL STRATEGY TO MEET THE AIR QUALITY STANDARDS	IV-1
	A. METHODOLOGY AND OBJECTIVES	IV-1
	B. DEVELOPMENT OF OPEN SPACE PLANS	IV-2

Preceding page blank

TABLE OF CONTENTS (CONTINUED)

Chapter Title Page

1. Land Availability. IV-2
2. Determining the Pollution Reductions Needed to Maintain Air Quality Standards. IV-7
3. The Hectare Vegetative Unit(Hypothetical). IV-9
4. Development of Open Space Plans. IV-16

C. SCHEMATIC OPEN SPACE SYSTEM. IV-37

V COST EFFECTIVENESS. V-1

A. OVERVIEW. V-1
B. OPEN SPACE LAND REQUIREMENTS FOR SO_2 REMOVAL. V-3
C. OPEN SPACE COST ELEMENTS V-3
1. Acquisition Costs. V-3
2. Capital Investment Costs V-4
3. Loss of Tax Revenues V-5
4. Annual Operating and Maintenance Costs . . V-5

D. AQMA PLAN COST ELEMENTS. V-5
E. COMPARISON OF RATE OF EXPENDITURE FOR OPEN SPACE AND AQMA PLANS. V-6
F. PRESENT WORTH COST-EFFECTIVENESS COMPARISON. . V-7
G. INTANGIBLE COSTS AND BENEFITS V-10
H. CONCLUSION. V-14

VI RECOMMENDATIONS. VI-1

A. AREAS REQUIRING ADDITIONAL WORK. VI-1

VII BIBLIOGRAPHY. VII-1

VIII APPENDIX - COST INFORMATION FOR COST EFFECTIVE ANALYSIS. VIII-1

A. OPEN SPACE COST INFORMATION. VIII-1
B. AIR QUALITY MAINTENANCE PLAN COST INFORMATION. VIII-2
1. Summary of Cost. VIII-2
2. Overall Reductions VIII-4
3. Limestone Scrubbing. VIII-6
4. Double Alkali Process. VIII-8
5. Wellman-Lord Process VIII-10
6. Citrate Process. VIII-11
7. Total Suspended Particulates VIII-13

TABLE OF CONTENTS (CONTINUED)

Chapter	Title	Page
IX	APPENDIX B--REVIEW OF COMSIS CORPORATION'S "SINK" FACTOR INFORMATION CONTAINED IN VOLUME I OF *Open Space as an Air Resource Management Measure*	IX-1
	A. PROJECT OFFICER'S INTRODUCTION	IX-1
	B. REVIEW OF "SINK" FACTORS BY DR. ERNEST W. PETERSON	IX-1
	1. SO_2 Uptake (Flux) Rates	IX-1
	2. Review of COMSIS Data	IX-3
	3. Conclusion	IX-8
	4. References	IX-11
	C. RESPONSE TO THE REVIEW BY DR. ROBERT S. DeSANTO AND DR. WILLIAM H. SMITH	IX-13
X	APPENDIX C--CORRECTIONS TO THE GAUSSIAN DIFFUSION EQUATION MATERIAL IN VOLUME II OF *Open Space as an Air Resource Management Measure*	X-1
	A. PROJECT OFFICER's INTRODUCTION	X-1
	B. CORRECTIONS TO THE MATERIAL BY JAMES L. DICKE	X-1

TABLE OF FIGURES

Figure	Title	Page
II-1	ST. LOUIS AIR QUALITY MAINTENANCE AREA.	II-4
II-2	LOCATION OF MAJOR INDUSTRIAL SOURCES.	II-5
II-3	1975 TOTAL SUSPENDED PARTICULATES AIR QUALITY CONCENTRATION.	II-10
II-4	1980 TOTAL SUSPENDED PARTICULATES AIR QUALITY CONCENTRATION.	II-11
II-5	1985 TOTAL SUSPENDED PARTICULATES AIR QUALITY CONCENTRATION	II-12
II-6	SO_2 POINT AND AREA LOCATIONS FOR AIR QUALITY ANALYSIS.	II-13
II-7	CO RECEPTOR LOCATIONS FOR AIR QUALITY ANALYSIS. . .	II-17
IV-1	SYNTHESIS 1: AVAILABLE LAND FOR PLANTING	IV-4
IV-2	SYNTHESIS 2: AVAILABLE LAND FOR PLANTING	IV-6
IV-3	ST. LOUIS AQMA EMISSIONS PROJECTION.	IV-8
IV-4	VEGETATIVE UNIT.	IV-11
IV-5	4 HECTARE GROUPING.	IV-12
IV-6	1985 TOTAL SUSPENDED PARTICULATES	IV-17
IV-7	TOTAL SUSPENDED PARTICULATES EMISSION DENSITY vs. ANNUAL CONCENTRATIONS.	IV-19
IV-8	1985 OPEN SPACE IMPROVEMENTS PLAN FOR TSP	IV-25
IV-9	LOCATION OF FUEL CONSUMERS.	IV-28
IV-10	HEDGEROW ILLUSTRATIONS.	IV-31

TABLE OF FIGURES (CONTINUED)

Figure	Title	Page
IV-11	BUFFER ILLUSTRATIONS.	IV-32
IV-12	NITROGEN DIOXIDE CYCLE.	IV-34
IV-13	INTERACTION OF NITROGEN DIOXIDE WITH HYDROCARBONS .	IV-35
IV-14	SCHEMATIC OPEN SPACE SYSTEM	IV-38

LIST OF TABLES

Table	Title	Page
II-1	ST. LOUIS AIR QUALITY MAINTENANCE AREA EMISSION - PROJECTION SUMMARY	II-8
II-2	SULFUR DIOXIDE AIR QUALITY PROJECTIONS	II-14
II-3	CARBON MONOXIDE AIR QUALITY PRCJECTIONS	II-16
II-4	PHOTOCHEMICAL OXIDANTS AIR QUALITY PROJECTION	II-18
III-1	PROPOSED ATTAINMENT/MAINTENANCE STRATEGY	III-2
III-2	MOBIL SOURCE EMISSION REDUCTIONS	III-10
IV-1	TOTAL VEGETATIVE SURFACE AREA IN ONE MODEL HECTARE	IV-15
IV-2	THE AMOUNT OF POLLUTANTS ABSORBED BY THE MODEL HECTARE	IV-15
IV-3	CALCULATIONS TO DETERMINE TSP EMISSIONS TAKEN UP USING OPEN SPACE DIRECTLY BENEATH $75\mu g/m^3$ AND ABOVE	IV-20
IV-4	CALCULATIONS TO DETERMINE TSP EMISSIONS TAKEN UP USING AVAILABLE OPEN SPACE DIRECTLY BENEATH $40\ \mu g/m^3$ AND ABOVE	IV-22
IV-5	DETERMINATION OF THE AMOUNT OF PARTICULATES ABSORBED BY STREET TREES	IV-26
V-1	COST ANALYSIS - OPEN SPACE PLAN FOR SO_2 REMOVAL	V-6
V-2	RATES OF EXPENDITURE	V-8
V-3	SO_2 - SUMMARY COMPARISON OF COST EFFECTIVENESS	V-11
VIII-1	SO_2 - REMOVAL AT RATED PERFORMANCE(85+% recovery)	VIII-2
VIII-2	SO_2 - REMOVAL AT RATED PERFORMANCE(51.3+% recovery)	VIII-3

I. INTRODUCTION, APPROACH & SUMMARY OF RESULTS

A. INTRODUCTION & ORGANIZATION OF REPORT

The work undertaken in this project has resulted in the preparation of three separate report Volumes and one Appendix Volume. Taken together, they cite and attempt to interpret all of the pertinent and accessible literature from the United States of America, and elsewhere, which we selected relating to the potential use of open space as a practical means to mitigate air pollution.

Volume III, this volume, is entitled Demonstration Plan and it hypothetically applies the findings and designs derived from Volumes I and II to a test city, St. Louis, Missouri. This hypothetical application of the demonstration plan includes a cost/effectiveness analysis of the combined open space/AQMA Plan. That aspect of this report attempts to evaluate some of the merits or problems of combining both natural and man-controlled management practices directed at mitigating air pollution. That evaluation was based on the best available data which we were able to secure and where limits must be placed on that data, those limits are explained in the text.

Volume I is entitled Sink Factors and presents the data collected from a number of manual and computerized literature searches. Most of the information presented in the other volumes was derived from the information contained in Volume I. Therefore, much cross referencing is made. Volume I contains tables of sink and emission factors which were developed based on the collected data, and it also contains tables of pollution sensitive and pollution resistant plant species derived from the surveyed literature. The separate Appendix Volume for Volume I presents complete abstracts of all the pertinent literature. It was decided to include as many abstracts as possible in order that our work might find as broad a utilization as possible by future researchers and, therefore, approximately 2,000 abstracts were selected for inclusion. Several thousands were discarded as not being especially pertinent after they had been reviewed.

Volume II is entitled Design Criteria and presents the essence of this study in the form of a workbook. It reviews the primary biological and design features which are crucial to the effective utilization of open space to mitigate air pollution. It presents generalized schemes for the design and location of buffer strips and other forms of open space and also illustrates air pollution mitigation by open space by identifying the mathematical procedures necessary in order to permit the incorporation of the appropriate sink factors into four generally used carbon monoxide diffusion models.

B. SUMMARY OF THE RESULTS

Volume III is a demonstration plan that has chosen St. Louis as a case study area to perform a comprehensive analysis of using open space measures as air quality maintenance tools. Volume III defines the existing environment in the case study area before proceeding to analyze the difference between addressing the air quality problem through traditional administrative control strategies or through the newly devised open space measures.

The area to transpose this hypothetical situation upon was chosen to be the St. Louis Air Quality Control Region (AQCR). The main reason for selecting St. Louis was that a trial Air Quality Maintenance Plan (AQMA Plan) had been completed for the area and an extensive Regional Air Pollution Study (RAPS) was being undertaken in the area which could provide an extensive data base for ambient air pollution levels. In addition to these reasons, the main planning agency in the area (the East-West Gateway Coordinating Council) was undertaking a revision of their plan of development for the region. It was felt that the proposed open space plan developed under this contract could be an input into a regional Open Space Plan developed as part of their plan of development.

The AQMA Plan developed in St. Louis performed three major functions. First it defined the air quality problem in St. Louis through utilization of an emissions inventory to determine present as well as future levels of air pollution. Secondly it explained how St. Louis was planning to attain the primary air quality standards. Finally it dealt with how those standards would be maintained through the inevitable growth pattern of the future.

The AQMA Plan reviewed monitoring data from Missouri and Illinois to determine trends in air quality. Monitoring data was available from eleven monitoring stations in the area. Sulfur dioxide (SO_2) air quality in Missouri was currently at or better than the annual standards. However, in Illinois several sites exceeded the primary standards for 24-hour measurements. Carbon monoxide (CO) values for 8-hour periods were recorded in 1972 that were almost twice the 8-hour standard. Oxidant concentrations also exceeded the standards and appeared to be increasing.

In addition to the baseline inventory, the AQMA Plan contained projections of emissions for Total Suspended Particulates (TSP), SO_2, CO, and Hydrocarbons for 1975, 1980, and 1985. The total emission projections are as follows:

	1975	1980	1985
Total Suspended Particulate	101,662	126,290	145,768
Sulfur Dioxide	797,080	1,119,844	1,149,053
Carbon Monoxide	585,403	358,507	278,162
Hydrocarbons	165,507	136,009	133,085

These emission projections were then used to derive air quality projections of ambient concentrations for 1975, 1980, and 1985.

In order to reduce excessive 1975 levels to the primary standards various strategies were proposed. For TSP and SO_2 since the problems were localized and were caused by individual sources, the action proposed was to continue to implement and enforce the State Implementation Plan (SIP) regulations. Subsequent monitoring results would indicate whether or not the standards were being achieved. If they were not, then hotspot regulations for individual sources would have to be implemented to bring isolated violations into compliance. From the monitoring data it was clear that CO and oxidant standards would not be met unless additional efforts were made. These efforts have materialized in the form of

Transportation Control Strategies. The purpose of these strategies is to reduce emission rates from individual vehicles through an inspection-maintenance program and to reduce the number of vehicles on the road, especially during rush hour through car pooling and transit incentives.

The final element of the AQMA Plan was the maintenance of standards through 1985. In this study an alternature to the proposed method of maintenance for particulate and sulfur dioxide is proposed and analyzed. The method of control in the AQMA Plan consisted of centralizing fuel burning sources. The degree of control needed was 44,000 tons/yr. of TSP and 186,000 tons/yr. of SO_2. The alternative method proposed in this study is to locate available open space acreage and plant that acreage with coniferous and deciduous trees. These trees will act as a sink to collect pollution out of the air as the air blows through the trees.

For the levels of reductions required an analysis of the two methods was conducted. The result of this analysis was used to perform a cost effectiveness study.

The basis of the AQMA Plan control strategy was the installation of control equipment on fuel burning sources to control 44,000 tons/yr. of TSP and 186,000 tons/yr. of SO_2. To illustrate this control strategy, it was determined that the 44,000 tons/yr. of TSP would be removed from a hypothetical coal burning power plant by electrostatic precepitators. The capital cost for the control equipment would be $2,519 million. The annual operating cost would be $310,733/yr. To recover 186,000 tons/yr. of sulfur dioxide, the Labodie Power Plant of Union Electric was theoretically determined by fitting the power plant with four (4) sulfur dioxide removal processes: limestone scrubbing, double alkali process, Wellman-Lord process, and citrate process. The median cost of these four processes is $20,875,000 with a corresponding operating cost of $9,482,000/yr.

For the alternature strategy of open space plantings it was determined that 122,517 hectares of land would be required to remove the 44,000 tons/yr. of particulates from the air. The total investment cost to plant this area would be close to $4,000,000,000. To remove the 186,000 tons/yr. of sulfur dioxide, 249 hectares of land will be needed for open space plantings. The capitol cost of this investment would be $3,087,500 with an annual operating operating expense of $477,525/yr.

From this comparative cost analysis it was concluded that open space plantings was a feasible method for removing sulfur dioxide; however, it was determined to be economically infeasibile to use open space plantings for the removal of particulates. It was made clear that mechanical devices at the source were the better control technology in terms of cost effectiveness for all control of particulates.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-76-028c	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Open Space as an Air Resource Management Measure - Demonstration Plan (St. Louis, Mo.) - Volume III		5. REPORT DATE January 1977 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robert S. DeSanto, Kenneth A. MacGregor, William P. McMillen, Richard A. Glaser		8. PERFORMING ORGANIZATION REPORT NO. H800-III
9. PERFORMING ORGANIZATION NAME AND ADDRESS COMSIS CORPORATION - Environmental Services 972 New London Turnpike Glastonbury, Connecticut 06033		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-2350
12. SPONSORING AGENCY NAME AND ADDRESS Strategies and Air Standards Division Office of Air Quality Planning and Standards Environmental Protection Agency Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This report is a demonstration plan for St. Louis, Mo. based on the collection and interpretation of data presented in the preceding two Volumes; Volume I - Sink Factors, and Volume II - Design Criteria. Based on the potential use of a hypothetical planting of street trees and idealized forest, an open space program is evaluated for St. Louis within the constraints of real world economics and the environment as it is presently exists in that urbanizing area.

References are made to data and interpretation in the preceding two Volumes, as appropriate, in support of the potential application of these guidelines to a major United States city confronted with various alternatives for air quality maintenance and environmental enhancement and/or stability.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Highways Forests Recreation Areas Residential Areas Costs Air Resource Management	Open Space Sinks Open Space Plan Recreation Plan Costs/Effectiveness Analysis Land Use, St. Louis, Mo. Greenbelts Air Pollutant Removal	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 151
	20. SECURITY CLASS (This page) Unclassified	22. PRICE PC A08 mF A01

EPA Form 2220-1 (9-73)

II. ST. LOUIS CASE STUDY AREA

A. SELECTION OF CASE STUDY AREA

After developing sink factors and planning design criteria, a demonstration study of open space as an air resource management technique was undertaken. The goal of this demonstration study was to maximize the use of open space in reducing ambient concentrations of air pollutants, subject to the overall population goals of the region under study. The first task of this demonstration study was to select an urban region to perform this analysis. The criteria for selection were: (1) that the area be an Air Quality Maintenance Area (AQMA) for at least sulfur dioxide (SO_2), photochemical oxidants, carbon monoxide (CO), and particulates (TSP), (2) the area had least a preliminary AQMA Plan completed, or was one of the sample case study areas (Baltimore, Denver, St. Louis or San Diego), so that a reduction of pollutants could be determined.

After discussions with the Project Officer, St. Louis was selected as the study area for the demonstration plan. The main reason for selecting St. Louis was that a trial AQMA Plan had been completed for the area and an extensive Regional Air Pollution Study (RAPS) was being undertaken in the area which could provide an extensive data base for ambient air pollution levels. In addition to these reasons, the main planning agency in the area (the East-West Gateway Coordinating Council) was undertaking a revision of their plan of development for the region. It was felt that the proposed open space plan developed under this contract could be an input into a regional open space plan developed as part of their plan of development.

After selecting St. Louis as the study area, an extensive search was undertaken of existing data sources that could serve as input into the demonstration plan. Contact was made with various agencies in the region including: (1) the East-West Gateway Coordinating Council; (2) the City of St. Louis, Air Pollution Control Division; (3) the State of Missouri, Air Conservation Commission; (4) the Environmental Protection Agency, Region VII, (Missouri), Region V, (Illinois); and RAPS Administrators; and (5) the State of Illinois, Environmental Protection Agency. The data collection effort was a three part process. The first part was the collection of relevant information to serve as a data base for physical planning. The second part was to determine the ambient concentration of air pollutants in the region for the present period. The final part was to determine what efforts were being made in the region to implement the trial AQMA Plan that had been previously developed, and accordingly to determine air pollution levels for future years.

Based on our discussions with the above agencies, it was decided that the trial AQMA Plan was to be used as the data base for ambient levels of air pollutants in the region for both the present and future years. It was also decided to use 1985 as the target year for the development of an open space plan because the preliminary AQMA Plan only contained predictions for that year. Other sources of data on ambient levels of pollutants were contained in documents received from the above agencies. However, in some cases the data were contradictory and/or outdated. RAPS had the potential of being an excellent source of data, but the study was not scheduled for completion in time for us to use its data for this project.

Physical planning data was collected from the East-West Gateway Coordinating Council and is discussed in Section IV-B of this report. Specific air quality maintenance measures as envisioned by local officials are presented in Chapter III-B.

B. AIR QUALITY SYNOPSIS FOR ST. LOUIS

The following discussion is a summary of the development of a trial AQMA Plan for the St. Louis Air Quality Control Maintenance Area (AQMA). This study was prepared for the Environmental Protection Agency by Alan M. Voorhees & Associates in December, 1974. Primary objectives of this study were to: (1) prepare a trial AQMA Plan for the St. Louis interstate AQMA, and (2) critic EPA guidelines for preparing an AQMA Plan.

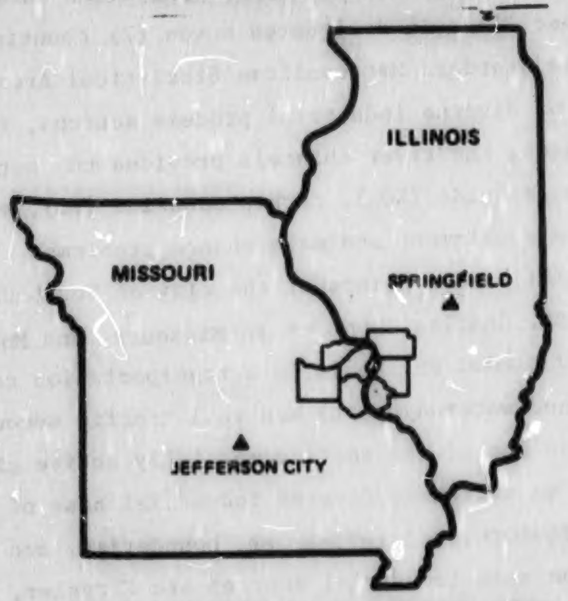
St. Louis was selected for study as an example of an interstate AQMA. The states of Missouri and Illinois designated seven (7) counties and St. Louis City which compromised the Standard Metropolitan Statistical Area (SMSA) as an AQMA. The concentration of diverse industrial process sources, transportation, and commercial activity along the river channels provides the potential for particulates (TSP), sulfur dioxide (SO_2), carbon monoxide (CO), and photochemical oxidants (Ox), air quality attainment and maintenance problems. The study area is shown in Figure II-1, and consists of the city of St. Louis and St. Louis, Franklin, Jefferson, and St. Charles counties in Missouri, and Monroe, St. Clair, and Madison counties in Illinois. St. Louis is a transportation center with river traffic(largest inland waterway port) and rail traffic second only to Chicago. St. Louis is also one of the most commercially active cities in the United States. It boasts an extremely diverse industrial base of food processers, metal processers and fabricators, oil refineries, boundaries, and chemical processing plants. Among the main industrial sources are Chrysler, Ford, General Motors, Monsanto-Queeny, Monsanto-Krummrich, Sacony Mobile, Granite City Steel, Clark Oil, and Amoco Oil, Shell Oil, Union Electric Co.(Rush Island Plant, Lobodie Plant, Portage Des Sioux Plant), River Cement Co., Pittsburgh Plate and Glass Industry, and St. Loe Lead Co. These major sources are illustrated in Figure II-2. As can be seen, most of them are located adjacent to the major rivers in the area.

St. Louis was not among the original urban areas required to submit a Transportation Control Plan (TCP) to provide for the attainment of CO and Ox standards. However, data from the expanded monitoring network for these pollutants indicated a potential attainment problem. Therefore, the Missouri Air Conservation Commission established an advisory committee to study the problem and prepare a transportation control plan for the AQCR.* An initial study was prepared by PEDCO, Environmental Specialist,Inc. for the attainment for CO and Ox standards. In June, 1975 the East-West Gateway Coordinating Council agreed to assist the Missouri Department of Natural Resources in the development of a TCP for metropolitan St. Louis. A technical draft of these strategies was finalized in April, 1976 and submitted to the Missouri Air Conservation Commission. The strategies include programs for inspection maintenance, parking management,

*Air Quality Control Region

FIGURE II-1

ST. LOUIS METROPOLITAN AREA


ILLINOIS
MISSOURI
SPRINGFIELD
JEFFERSON CITY

ST. LOUIS AIR QUALITY MAINTENANCE AREA

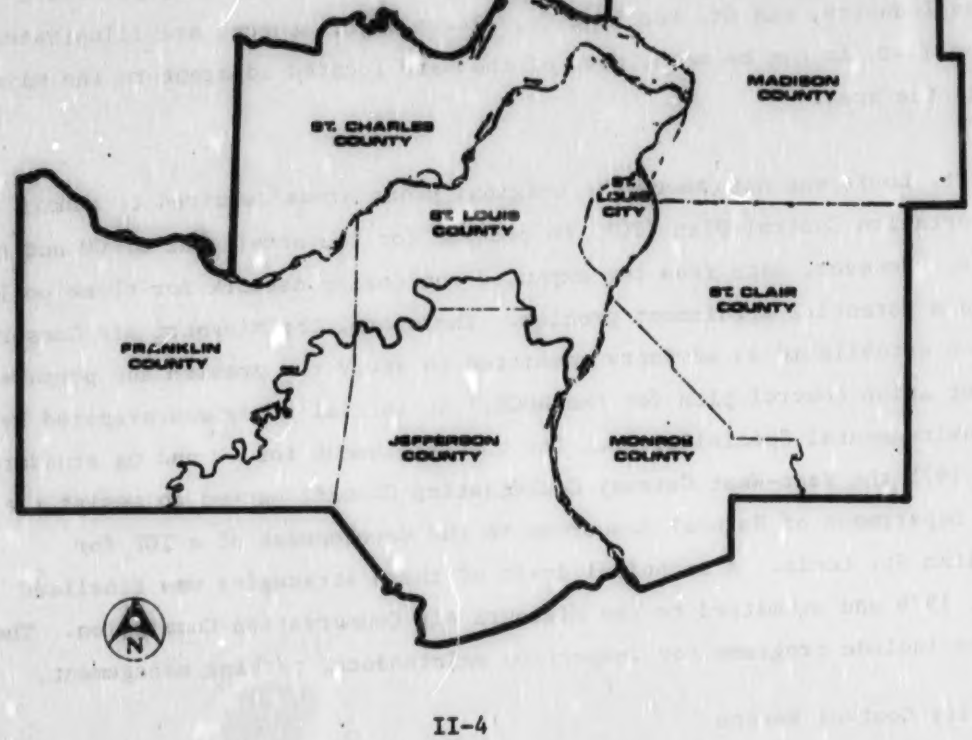
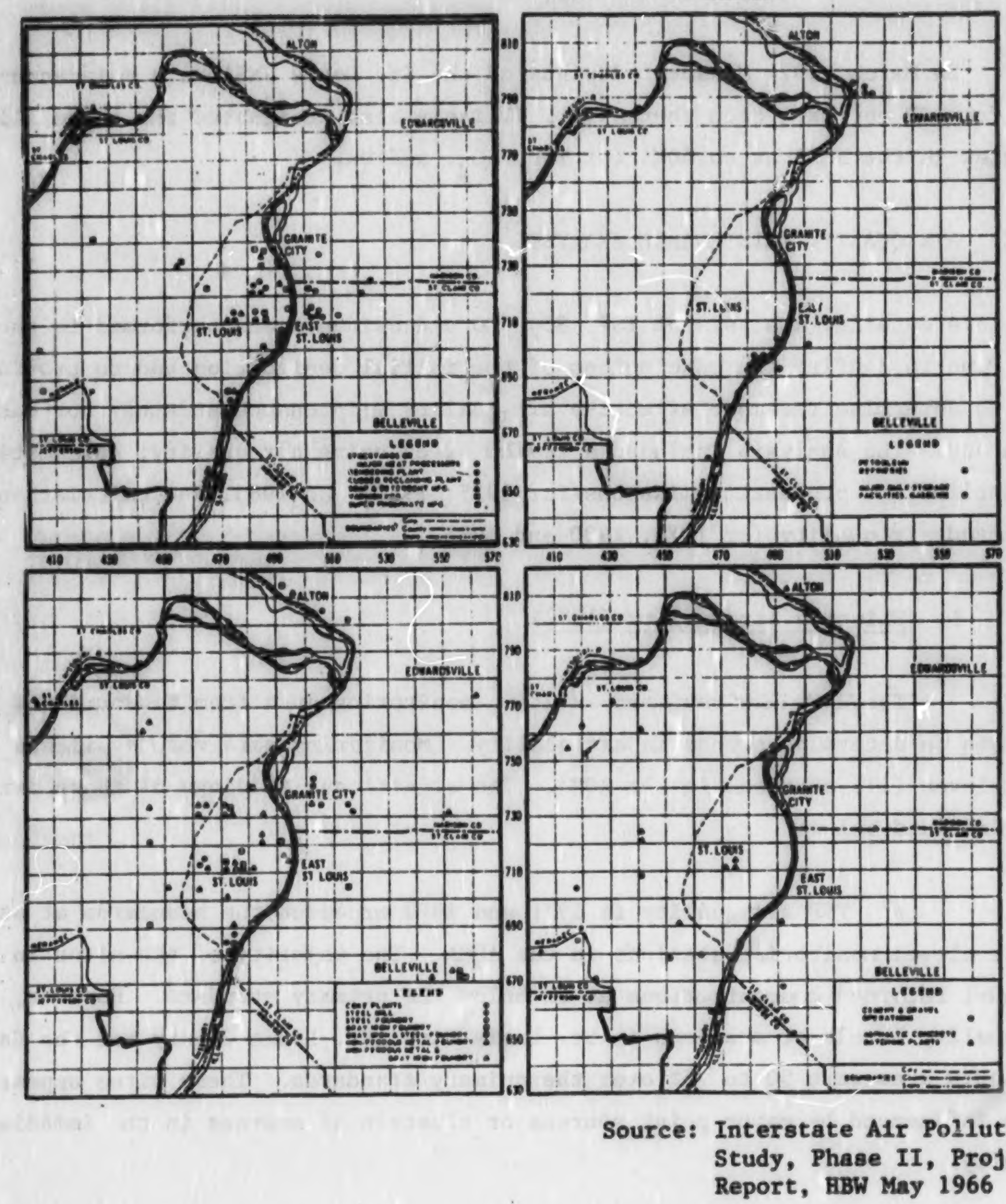

MADISON COUNTY
ST. CHARLES COUNTY
ST. LOUIS CITY
ST. LOUIS COUNTY
ST. CLAIR COUNTY
FRANKLIN COUNTY
JEFFERSON COUNTY
MONROE COUNTY
N

FIGURE II-2

LOCATION OF MAJOR INDUSTRIAL SOURCES


ALTON
ST CHARLES CO
ST LOUIS CO
EDWARDSVILLE
GRANITE CITY
MADISON CO
ST CLAIR CO
ST. LOUIS
EAST ST. LOUIS
BELLEVILLE
ST LOUIS CO
JEFFERSON CO
LEGEND
STOCKYARDS OR MAJOR MEAT PROCESSORS
RENDERING PLANT
SOAP & DETERGENT MFG.
VARNISH MFG.
SUPER PHOSPHATE MFG.
PETROLEUM REFINERIES
COKE PLANTS
STEEL MILL
STEEL FOUNDRY
GRAY IRON FOUNDRY
GRAY IRON & STEEL FOUNDRY
NON-FERROUS METAL FOUNDRY
CEMENT & GRAVEL OPERATIONS
ASPHALTIC CONCRETE BATCHING PLANTS
BOUNDARIES
City
County
State
810
790
770
750
730
710
690
670
650
630
410
430
450
470
490
510
530
550
570

Source: Interstate Air Pollution Study, Phase II, Project Report, HBW May 1966

reserved bus lanes, improved transit, car-pooling, signal sychronization, and rescheduled hours. These strategies are presently under review by the Missouri Air Conservation Commission, as well as local agencies, as possible measures to attain CO and Ox levels in the AQCR.

In March, 1974 Missouri designated the St. Louis SMSA as a maintenance area for TSP and Ox. Soon thereafter, Illinois also designated the three Illinois counties in the SMSA as an AQMA for TSP, SO_2, and Ox.

C. AIR QUALITY MAINTENANCE ANALYSIS

A detailed analysis of TSP, SO_2, CO and oxidants was performed in the AQMA Plan to confirm the conclusions of the initial designation and to provide data to determine the most effective air quality maintenance strategy for each pollutant. The analysis included a review of existing air quality, calculation of baseline and projected emissions for 1975, 1980, and 1985, and calculation of projected air quality for 1975, 1980 and 1985.

1. Existing Air Quality (1972).

The AQMA Plan reviewed existing monitoring data from Missouri and Illinois to determine trends in air quality. Monitoring data were available from eleven (11) stations in the AQMA. The significant findings of these data are discussed below:

a. TSP air quality in 1971 and 1972 exceeded the standards at several of the eleven monitoring stations in the AQMA. The majority of the sites in Missouri recorded concentrations at or below the primary standard. However, air quality levels at stations in St. Louis City, St. Louis County and the East St. Louis area were 50 to 75% over the primary standards. These sites appeared to be influenced by major point sources or clusters of sources in the immediate vicinity.

b. SO_2 air quality in Missouri was currently at or better than the annual standards. However, Illinois reported several site concentrations exceeding the primary standards for 24-hour measurements. These sites appeared to be influenced by major point sources.

c. CO values for 8-hour periods were recorded in 1972 that were almost twice the 8-hour standard. Urban "hotspots" associated with mobile sources were identified.

d. Oxidant concentrations also exceeded the standards and appeared to be increasing.

2. Emissions Projections.

The general approach to projecting emissions for all four pollutants applied the following procedure:

- Estimate a 1975 baseline inventory for all sources, assuming the sources are in compliance with existing regulations.
- Develop growth factors for each source category from available growth data.
- Apply the growth factors to the 1975 baseline inventory to obtain projected emissions from each source category.

Using the procedures discussed above, emissions were projected for 1975, 1980 and 1985 for each pollutant and source category. These data are presented in Table II-1. Conclusions drawn from the projections are:

a. TSP areawide total emissions increase through 1975. Major increases are attributable to point sources and are expected to occur in the vicinity of existing "hotspots."

b. SO_2 emissions projections reflect significant increases in power plant capacity projected to occur through 1985.

c. CO areawide totals decrease sharply and continuously through 1985 due to the impact of the Federal Motor Vehicle Control Program (FMVCP).

TABLE II-1

ST. LOUIS AIR QUALITY MAINTENANCE AREA

EMISSION PROJECTION-SUMMARY

Source Category		Emissions, Tons per year 1975	1980	1985
		Total Suspended Particulate		
Point Sources		50,329	57,972	71,617
Area Sources		18,955	20,404	23,563
Power Plants		20,348	34,064	34,863
Mobile Sources:	Highway	8,383	9,622	10,823
	Off-highway	3,647	4,228	4,902
	TOTALS	101,662	126,290	145,768
		Sulfur Dioxide		
Point Sources		194,046	204,013	218,452
Area Sources		40,155	44,510	50,063
Power Plants		577,190	864,748	873,000
Mobile Sources:	Highway	2,065	2,371	2,666
	Off-highway	3,624	4,202	4,872
	TOTALS	797,080	1,119,844	1,149,053
		Carbon Monoxide		
Point Sources		46,821	50,870	59,734
Area Sources		28,808	27,565	27,799
Power Plants		1,641	1,641	1,700
Mobile Sources:	Highway	476,242	241,459	146,070
	Off-highway	31,891	36,972	42,859
	TOTALS	585,403	358,507	278,162
		Hydrocarbons		
Point Sources		40,208	50,330	55,009
Area Sources		30,389	32,153	35,370
Power Plants		1,191	1,395	1,666
Mobile Sources:	Highw[illegible]	82,502	39,217	25,956
	Off-highway	11,217	13,004	15,076
	TOTALS	165,507	136,009	133,085

d. Total HC projected emissions decrease through 1985. Point and area source emissions increase gradually, while mobile source emissions decrease significantly.

3. Air Quality Projections.

A number of techniques were used for the projection of air quality from emission data. For TSP, the projections were accomplished through application of statistical relationships between TSP emissions density and concentration. A curve was developed which displayed this relationship and was used to estimate annual concentrations at the center of each selected subarea in the AQMA. Isopleths were drawn based on concentrations at subarea centers. These isopleths display the mean annual TSP concentration distribution in the St. Louis AQMA. Figures II-3, II-4 and II-5 show distribution of TSP mean annual concentrations for 1975, 1980 and 1985, respectively.

The projection of air quality concentrations for SO_2 was accomplished by applying two air quality diffusion models: Miller-Holzworth for the St. Louis central urban area of the Wood River refinery complex, and the Pasquill-Gifford plume dispersion for four significant point sources. These two projection methods required calculations of concentrations from given equations. The Miller-Holzworth equation calculates annual average areawide concentrations of SO_2 from emission density, mixing depth, urban size, and mean annual wind speed. The Pasquill-Gifford plume dispersion calculates a maximum 24-hour average concentration of SO_2 from wind speed, plume rise, emissions rate, stack parameters, meteorological stability, and assumes a Gaussian plume.

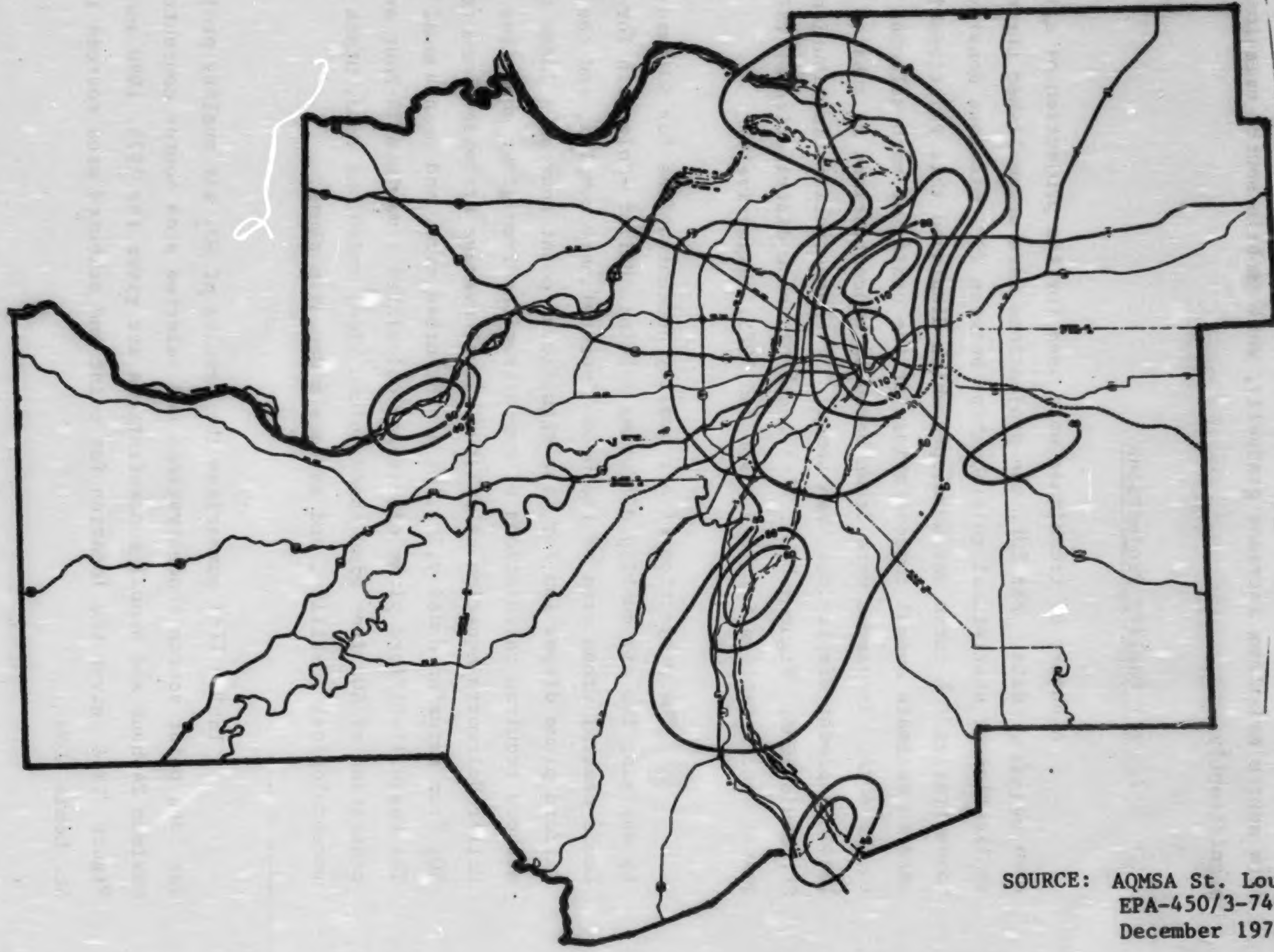
Table II-2 summarizes the results of SO_2 air quality projections for both point source concentrations and selected area source concentrations. Maximum 24-hour and annual concentrations are given for 1975, 1980 and 1985. Figure II-6 gives the location for point and selected area sources in the St. Louis AQMA.

CO air quality projections were calculated for 1975 at nine selected receptor sites using the APRAC 1A diffusion model. CO concentrations in 1980 and

FIGURE II-3

1975 TOTAL SUSPENDED PARTICULATES

AIR QUALITY CONCENTRATIONS

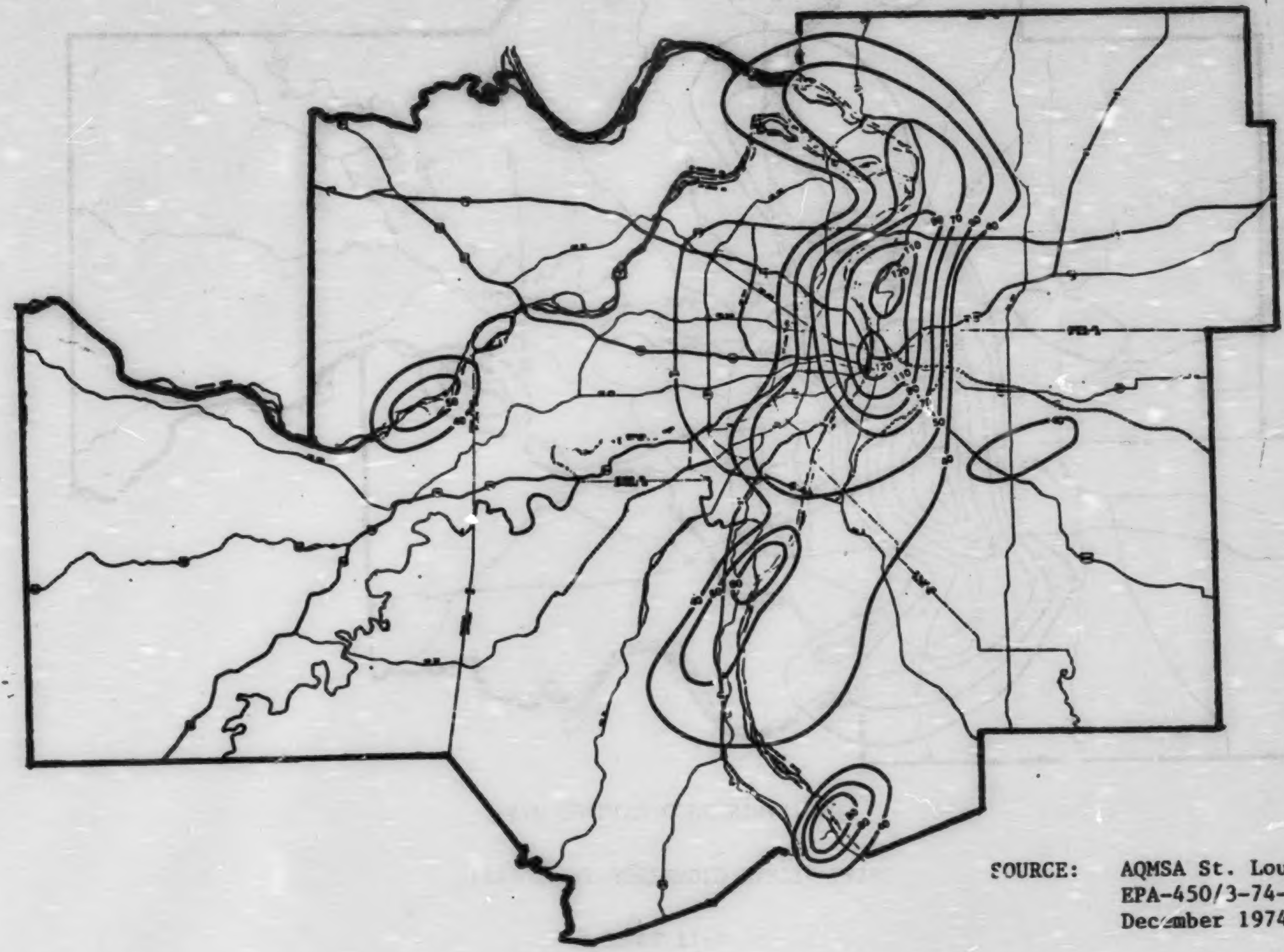


SOURCE: AQMSA St. Louis
EPA-450/3-74-052
December 1974

FIGURE II-4

1980 TOTAL SUSPENDED PARTICULATES

AIR QUALITY CONCENTRATIONS

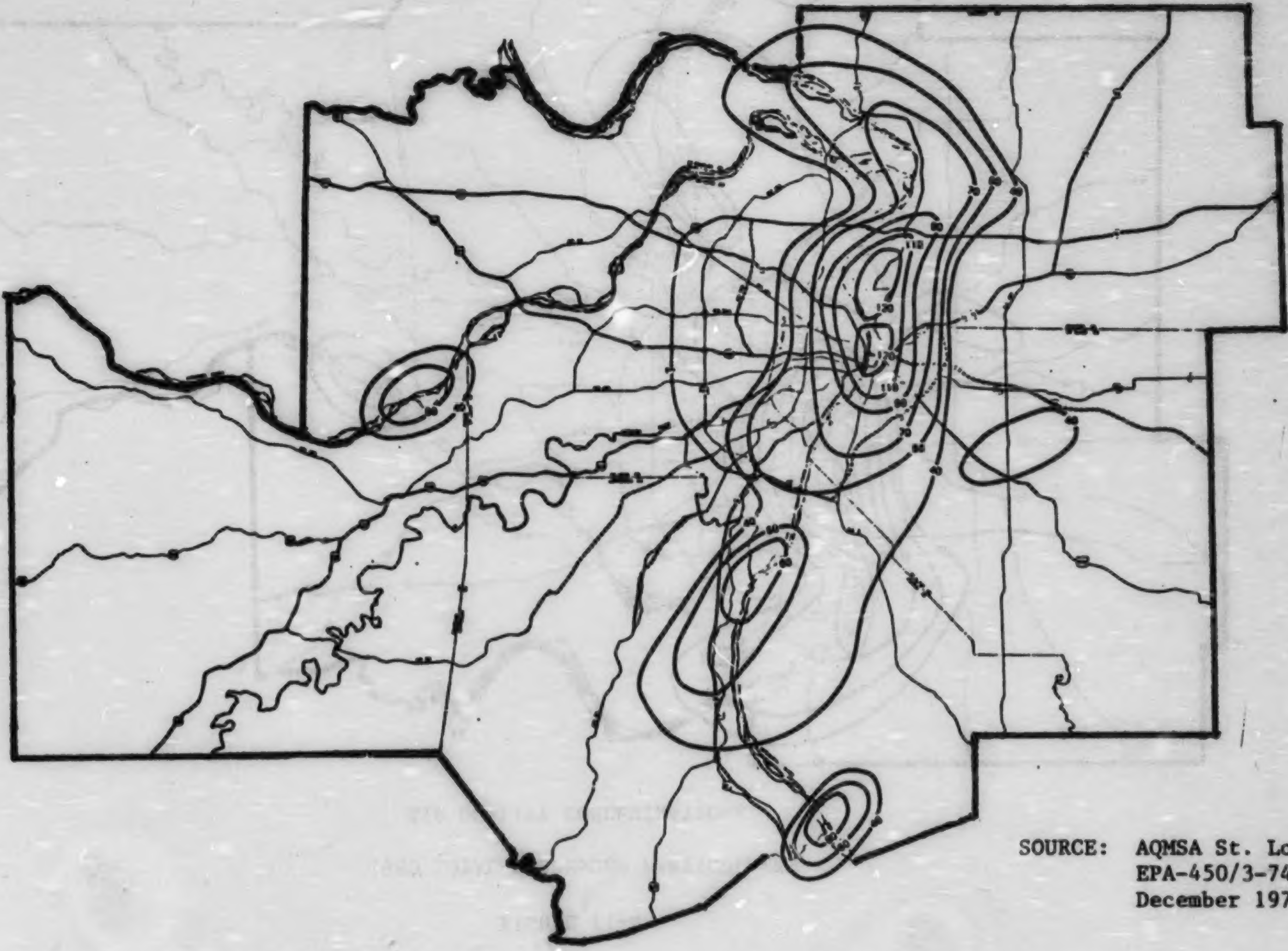

70
110
120
120
110
50

SOURCE: AQMSA St. Louis
EPA-450/3-74-052
December 1974

FIGURE II-5

1985 TOTAL SUSPENDED PARTICULATES

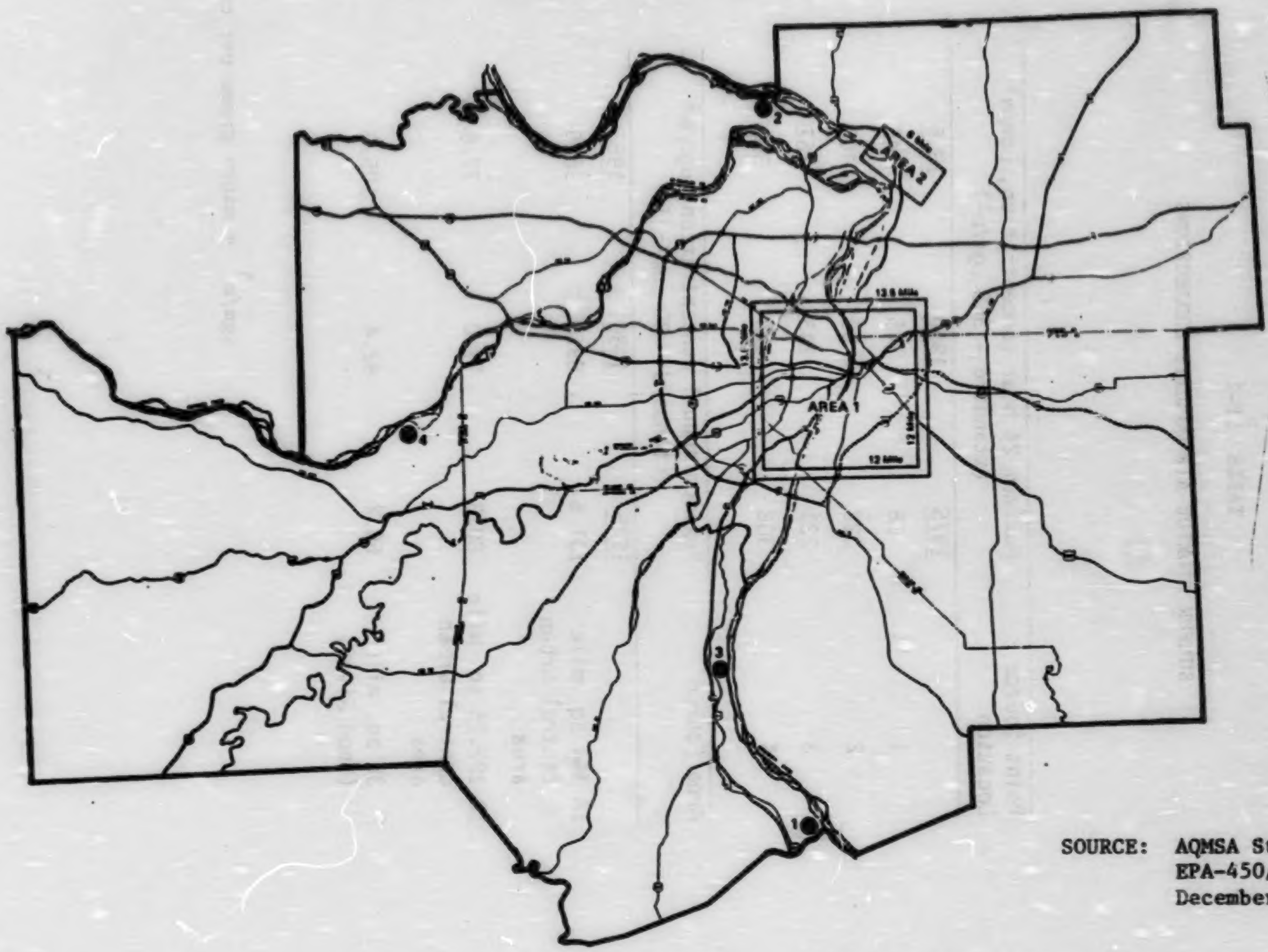
AIR QUALITY CONCENTRATIONS


110
120
120
110
90
70
40

SOURCE: AQMSA St. Louis
EPA-450/3-74-052
December 1974

FIGURE II-6

SO_2 POINT AND AREA LOCATIONS FOR AIR QUALITY ANALYSIS


AREA 1
AREA 2
13.5 Miles
12 Miles
6 Miles
1
2
3
4

SOURCE: AQMSA St. Louis
EPA-450/3-74-052
December 1974

TABLE II-2

SULFUR DIOXIDE AIR QUALITY PROJECTIONS

Point Source Location	Maximum 24 hour concentration, μgm/m³ (standard - 365 μgm/m³)		
	1975	1980	1985
1	38	145	145
2	322	400	400
3	221	243	262
4	308	308	308

Area Source	Maximum annual concentration, μgm/m³ (standard - 80 μgm/m³)		
	1975	1980	1985
1A 144 sq. mile central urban area	101.6	89.8	98.5
1B 182.25 sq. mile central urban area	80.3	71.0	77.8
2 36 sq. mile (Wood River)	66.2	82.4	105.0

μgm/m³ = micro grams per cubic meter

1985 at these receptors were extrapolated from the 1975 estimates using the following procedure:

- Assume worst case meteorological conditions do not vary
- Assume concentrations of CO are directly proportional to emissions of CO under worst-case meteorological conditions
- Calculate 1975, 1980 and 1985 CO emissions in the vicinity of the selected nine receptors using subcorridor analysis technique developed in the AQM Plan
- Apply the corresponding percent change in emissions to the 1975 concentration of each receptor to obtain 1980 and 1985 concentrations.

Table II-3 shows the maximum 8 hour CO concentrations for the selected receptors for 1975, 1980 and 1985. The projections for 8-hour carbon monoxide concentrations generally exceed the standard in 1975; by 1980 and 1985, concentrations are well below the standard. Figure II-7 shows the location of the receptor sites listed in Table II-3 .

The projection of air quality concentration for photochemical oxidants was accomplished by applying Appendix J of the Federal Register 40 CFR 21, Regulations on Preparation of Implementation Plans. This Appendix presents the relationship between percent reduction in hydrocarbon emissions and maximum one-hour photochemical oxidant concentrations.

Since EPA defined oxidants as an area wide problem, the AQMA Plan used the areawide emissions from Table II-1 to determine percent emission reductions from the air quality baseline year of 1972 to 1975, and 1980 to 1985. The 1972 second highest 1-hour concentration of 300 micrograms per cubic meter was used as the base line.

TableII-4 shows the projected 1-hour oxidant concentration for 1975, 1980, and 1985 that was projected in the AQM Plan. The oxidant concentrations are approaching the standard by 1985, but do not attain it.

TABLE II-3

CARBON MONOXIDE AIR QUALITY PROJECTIONS

Receptor	Location	Maximum Eight Hour Concentration, ppm (Standard - 9 ppm)		
		1975 (a)	1980 (b)	1985 (b)
1	CAMP	10.8	5.44	3.15
2	I-70 & I-270	7.2	3.75	2.37
3	I-70 & Shreve	9.6	4.90	2.80
4	Lindbergh & Linferry	12.8	6.95	4.30
5	Hunter Ave. & Clayton	10.5	5.46	3.22
6	St. Ann	9.9	5.25	3.19
7	I-244 & Manchester	10.8	5.88	3.69
8	S.L. airport	8.8	4.60	2.76
9	U.S. 40 & Grand	10.9	4.52	2.37

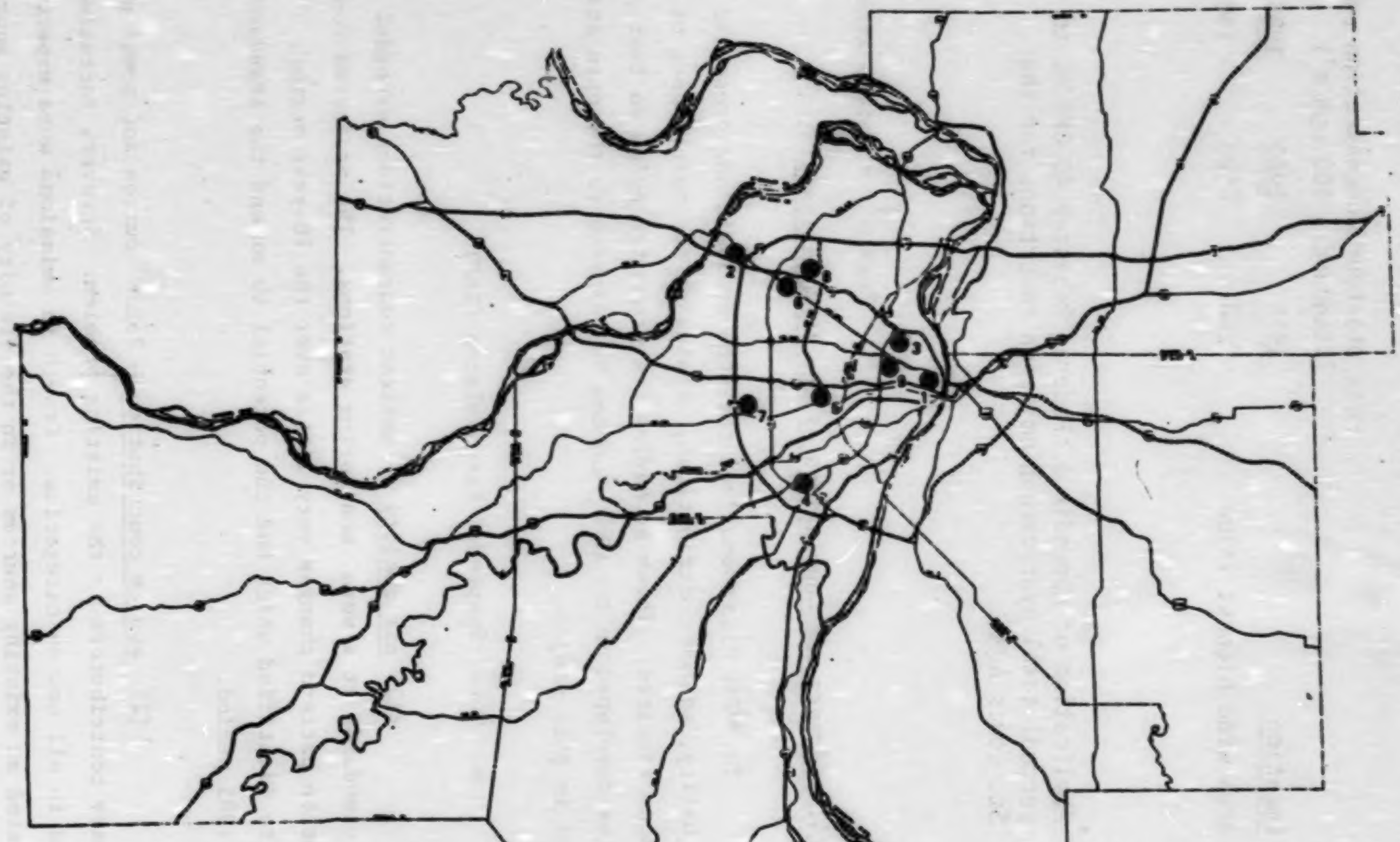
(a) 1975 concentrations were generated using APRAC-IA urban diffusion model

(b) 1980 and 1985 are extrapolations of the APRAC-IA 1975 data using percent change in emissions from mobile sources generated from the subcorridor emissions analysis

FIGURE II-7

CO RECEPTOR LOCATIONS FOR

AIR QUALITY ANALYSIS



SOURCE: AQMSA St. Louis
EPA-450/3-74-052
December 1974

TABLE II-4

PHOTOCHEMICAL OXIDANTS
AIR QUALITY PROJECTIONS*

	Peak one hour Concentration μgm/m³ * (Standard - 160 μgm/m³)		
Location	1975	1980	1985
Area wide highest value	240	190	180

*Application of Appendix J. Federal Register 40 CFR 51 to percent total hydrocarbon emission reductions for the St. Louis AQMA.

*μgm/m^3 = micro-grams per cubic meter

4. Summary and Conclusions of the AQMA Analysis.

The AQMA Plan summarized the AQMA analysis and presented conclusions on air quality, source contributions, attainment and maintenance of standards, and actions required. These summaries are presented below so that the maintenance strategies developed in the AQMA Plan can be compared to the open space measures developed in this project

a. Total Suspended Particulates (TSP)

(1) air quality - Ambient concentrations exceeded the primary standards at several monitoring stations. The projected concentration distribution pattern changes very little over the 10-year period. "Hotspot" areas were identified which had the potential to exceed the standards during the 1975 to 1985 period.

(2) source contribution - Point sources and power plants were the primary contributors to the existing problem. However, increases were projected in all source categories. Growth in emissions were expected to be concentrated at existing sources or in the vicinity of existing sources.

Growth accounts for less than 20 percent of projected total emissions in 1985. The contribution of fugitive dust to ambient concentrations was not known at the time.

(3) attainment and maintenance of standards - The primary standards were projected to be attained by 1975 and maintained throughout the following 10-year period in most of the AQMA. However, "hotspot" areas were identified where the primary standards were projected to be exceeded beyond the 1975 compliance schedule. Because the growth in emissions were projected to be concentrated in these "hotspot" areas, maintenance of the standards would be a problem. Secondary standards were projected to be exceeded throughout the 10-year period in large portions of three counties and the city of St. Louis surrounding the "hotspot" areas.

(4) actions required - An attainment and maintenance strategy was required for the "hotspot" areas. A strategy was needed to maintain the secondary standard for TSP in the area immediately surrounding the "hotspot."

b. sulfur dioxide (SO_2)

(1) air quality - ambient concentrations of SO_2 on the Missouri side of the AQMA were all below the standards. Concentrations at isolated sites in the Illinois portion of the AQMA exceeded the primary standard. Air quality projections were highly dependent on the sulfur oxide emissions from isolated sources and indicated that a "potential" to exceed the standards existed only in the vicinity of these sources. No regionwide maintenance problem is projected.

(2) source contribution - Power plants and several large industrial point sources accounted for all significant contributions to existing and projected emissions of sulfur oxides. Growth in emissions was projected to be significant due to power plant expansions.

(3) attainment and maintenance of standards - SO_2 standards were expected to be attained and maintained throughout the AQMA. Exceptions may recur in the vicinity of major power plants or specific point sources.

(4) actions required - A regionwide maintenance strategy was not required. However, more extensive monitoring and surveillance of major sources was required to ensure maintenance of the short-term standards in the vicinity of sources. Interim measures may have been required to attain and maintain in the "hotspots."

c. carbon monoxide (CO)

(1) air quality - Eight-hour standards were currently exceeded at several monitoring stations throughout the AQMA. Projected concentrations indicated several areas would exceed the eight-hour standard in 1975. All selected receptor sites were projected to be well below the standards by 1980. Maximum concentrations were associated with major highways and intersections.

(2) source contribution - Mobile sources were the primary contributor to CO emissions in the AQMA and would still account for more than 50% of total emissions by 1985.

(3) attainment and maintenance of standards - Once the eight-hour CO standards were attained, the continued decline in mobile source emissions would assure maintenance to at least 1985.

(4) actions required - A Transportation Control Plan (TCP) was in the process of being developed to provide attainment of the CO standards. The TCP was expected to be adopted by February 1975. A regional maintenance strategy was not required at the time.

d. photochemical oxidants (0_x)

(1) air quality - peak-hour oxidant concentrations exceeded the standard and limited air quality trend data indicated increasing values. Oxidant values were projected to decrease due to decreases in total hydrocarbon emissions. However, the decreases were projected to be insufficient to attain the standard.

(2) source contribution - Mobile sources were the most significant contributor to total regional hydrocarbon emissions. However, stationary point and area sources were suggested to be more significant by 1985 as mobile source controls became more effective.

(3) attainment and maintenance of standards - The oxidant standard could not be attained or maintained with the SIP control measures. Uncontrolled (no TCP) projected oxidant concentrations exceeded the standard beyond 1985.

(4) actions required - A Transportation Control Plan (TCP) was required for attainment and a maintenance strategy was required.

III. AIR QUALITY MAINTENANCE PLAN AND RECENT DEVELOPMENTS IN ST. LOUIS

The air quality analysis in Section II indicated that attainment of the primary standards for TSP, SO_2, CO and oxidants could not be achieved by 1975. In addition, maintenance strategies were required for TSP, SO_2 and oxidants. Therefore, the AQMA Plan reviewed existing and proposed attainment plans and evaluated alternative strategies. Following the development of the AQMA Plan certain maintenance strategies were officially adopted and/or were developed for consideration by the appropriate personnel. The following section will review the attainment and maintenance plans developed in the AQMA Plan and will document the strategies that have been or will be adopted in the area according to local officials.

A. AIR QUALITY MAINTENANCE PLAN

The first step in the development of the AQMA Plan was to review the existing air quality plans to determine if they were sufficient to attain and/or maintain air quality standards in the region. After reviewing these plans, it was then necessary to review possible maintenance strategies and evaluate their application in the St. Louis AQMA. Finally, a proposed maintenance plan was developed to provide sufficient emission reduction to account for the projected growth or prevent that growth from occurring in areas where the ambient air quality was at or near the standard. The attainment and maintenance strategies developed for the St. Louis AQMA in the AQMA Plan are detailed below and summarized in Table III-1.

1. Attainment Plans.

a. Particulates (TSP)

The original projections included in the Missouri and Illinois State Implement Plans (SIP) predicted attainment of the TSP standards by 1975. These projections were dependent upon data base, analysis, control technique, and compliance schedule assumptions. In addition, it was assumed that the relationship between emissions and air quality was adequately defined by the analysis technique and the meteorological conditions given as representative of the worse case.

TABLE III-1

PROPOSED ATTAINMENT/MAINTENANCE STRATEGY

Pollutant	Attainment	Interim Maintenance	Long-Term Maintenance
Total Suspended Particulates (TSP)	SIP Regulations enforcement, extended monitoring and surveillance	Implement "hot-spot" regulations	Long-term comprehensive approach
Sulfur Dioxide (SO_2)	Enforcement of SIP Regulations, extended monitoring and surveillance	Implement "hot-spot" regulations, burn municipal refuse in power plants, SO_2 reduction at power plants	Long-term comprehensive approach
Carbon Monoxide (CO)	Transportation Control Plan (TCP)	(Required if TCP Strategy II or III* are not implemented). Indirect Source Review, exclusive bus/carpool lanes	Long-term comprehensive approach
Photochemical Oxidants (O_x)	Transportation Control Plan (TCP)	(Required if TCP Strategy III* is not implemented). HC stationary Source Control	Long-Term comprehensive approach

---

*As described in PEDCo "Attainment Study"
STRATEGY II -- Carpool incentive program plus indirect actions occurring with stimulus of plan.
STRATEGY III -- STRATEGY II plus maximum technically demonstrated stationary source control.

Any one of these assumptions could have been too optimistic. Because the analysis performed in the air quality maintenance plan was subject to the same conditions it could not be assured that the 1975 air quality would exceed the standards. Therefore, no TSP control measures were suggested at that time. It was recommended that the monitoring and surveillance program be expanded to determine if the air quality would exceed standards. It was, however, recommended that a fugitive dust inventory be completed for the region as part of this monitoring program.

b. Sulfur Dioxide (SO_2)

The SIP for Illinois and Missouri both projected attainment of SO_2 standards by 1975. Current air quality at the time was below the primary and secondary standard in Missouri; however, 1972 air quality exceeded the primary standards at several sites in the Illinois portion of the AQMA. The Illinois EPA felt these violations were related to individual sources.

The analysis performed in the AQMA Plan concluded that the primary standards would not be achieved by 1975 at several points in the AQMA due to source orientated problems. In addition, scheduled expansions at power plants provided the potential for short term standards to be violated depending upon individual source operational characteristics.

It was concluded that the attainment of SO_2 standards was a specific source oriented problem. Efforts were then underway to determine source compliance with existing regulations. Therefore, no new attainment measures were required at that time.

c. Carbon Monoxide (CO) and Photochemical Oxidants (Ox)

St. Louis was not among the original group of cities required to submit transportation control plans to attain and maintain CO and oxident standards. Ambient data collected during the development of the AQMA Plan from expanded monitoring networks suggested an attainment problem did exist for CO and oxidants. Therefore, the Missouri Air Conservation Commission in cooperation with the Illinois EPA and Area Transportation Planning Community representatives prepared a Transportation Control Plan (TCP).

This TCP was developed after the submission of the AQMA Plan. Suggested strategies from the TCP are included in this Section on Developments in St. Louis Since Submission of the AQMA Plan.

2. Recommended Maintenance Strategies.

After reviewing the existing attainment plans, the AQMA Plan included a program which was considered the best approach to the attainment and maintenance of air quality in the St. Louis AQMA. This program included:

- Full implementation and enforcement of all attainment plan measures included in the state implementation plans
- Expanded monitoring and surveillance through the RAPS/RAMS programs
- Long-term comprehensive approach to air quality maintenance
- Interim measures to ensure maintenance during the period required for development and full implementation of the long-term approach

The following sections describe the interim maintenance measures and administrative approach developed in the AQMA Plan.

a. Interim Measures

(1) municipal refuse (SO_2 control at power plants)

In approximately 1971 the EPA, Union Electric, and the city of St. Louis embarked on a pilot project to determine the feasibility of using municipal solid waste as a fuel for power plant boilers. The results of the experiment were made public in early 1974. They indicated that it was feasible and, in fact, economically profitable for Union Electric. In 1970, it was projected that Union Electric would have a system organized whereby all the public and refuse collectors would take their refuse to a sorting station where the burnable refuse would be separated from the non-burnable. The non-burnable, principally metals, would be sold as scrap, while the burnables would be taken to the main power plants. This fuel would satisfy almost 10% of the fuel requirements for the generators, with the remainder being coal. This use of refuse as a fuel was projected to SO_2 emissions by a minimum of 5% and a maximum of 10% at the power plants. At the same time, the data indicated that TSP emissions at the plant would not be significantly increased.

(2) sulfur dioxide (SO_2) emission reduction at three (3) major power plants

The projected emission inventory data for the Labadie, Meramec, and Sioux power plants of Union Electric did not contain a future reduction to account for SO_2 control of stack gases, even though the three plants would be in violation of Missouri safe regulations for allowable SO_2 emission rates in the St. Louis area (2.3 lbs/10^6BTU input). EPA, therefore, issued a notice to Union Electric Company which indicated that these three plants may prevent attainment of NAAQS.

The AQMA Plan surmised that if emission reductions were required at the three plants they would probably occur prior to 1978, and therefore should be considered as interim maintenance measures. These potential reductions represented a large portion of total projected regional SO_2 emissions. It was stated that compliance with the existing regulations would bring about the following percentage reductions (from the 1975 projected emissions): Labadie - 56%, Meramec - 6%, Sioux - 53%.

The AQMA Plan stated that this was equivalent to approximately 383,000 tons/yr. of SO_2 eliminated for all three plants, or 38% of projected 1975 SO_2 emission in the AQMA.

(3) indirect source review (carbon monoxide control)

The AQMA Plan suggested that the Transportation Control Plan, scheduled to be submitted in February 1975, would provide for attainment of CO and oxidant standard by at least 1977. The emission analysis indicated that the total emissions of CO for the AQMA, the individual counties and in the individual subcorridors would decrease from the attainment date until 1985. This continued reduction in emissions primarily reflect the greater impact of the Federal Motor Vehicle Control Program (FMVCP).

Based on the projected decrease in emissions, and on assumptions that a Transportation Control Plan would be approved, the only remaining problem with maintenance of the CO air quality standard through the year 1985, was suggested to be a microscale problem of individual indirect sources. Therefore, it was suggested, that as a part of the AQMA Plan, an indirect source program be implemented.

(4) exclusive/car pool lanes (carbon monoxide control)

This control measure was suggested to help reduce the number of vehicle trips made in AQMA, especially in the morning and evening peak hours. It was suggested that one freeway in St. Louis, I-70, was well suited for such a conversion to bus/car pool lanes. The freeway had two center reversible lanes that were used as express lanes for vehicles during the peak hours. Traffic volumes along I-70 in St. Louis approached 100,000 vehicles/day and it was stated that a 6% reduction, especially during the morning and evening peak hours, could be achieved using these percentages. It was concluded that this would mean 4,320 less automotive VMT on the freeway during the AM peak period.

It was also suggested that some thought should be given to providing preferential bus usage on curb lanes on major city streets. This measure would increase the speed of buses, thereby making them attractive to the public as a means of transportation, and would increase ridership and reduce the overall number of vehicle trips made in the AQMA. In addition, it was reported that approximately 160,000 VMT/day could be eliminated along major routes through the increased use of mass transit.

(5) cost-effective stationary source hydrocarbon controls (oxidant reduction)

The AQMA Plan referenced a previous study accomplished in St. Louis wherein it described optimum control by major stationary sources in the area for CO and oxidants. The major objection to these measures was the seventy (70) million dollar cost estimate. These controls were described as, "maximum, technically demonstrated, control technology." The AQMA stated that if these controls were adopted as part of the proposed TCP, they would provide sufficient control, together with new Federal source performance standards, for these sources to attain and maintain the oxidant standard through at least 1985. If, however, they were not adopted, the AQMA Plan suggested that some form of stationary source HC control would be required as a maintenance measure to account for the projected growth in this source category. In that case, it was recommended that a cost/effective level of control be negotiated with each source.

b. Recommended Long-Term Comprehensive Approaches to Maintenance

The AQMA Plan concluded that a regional comprehensive approach to air quality maintenance for the St. Louis AQMA was required if long-term land use and environmental objectives were to be attained. It was suggested that the first step in the implementation process require the development of a revised or updated regional comprehensive plan using air quality maintenance as a constraint. This could be accomplished by an evaluation of alternatives for environmental and, in particular, air quality impact. The then existing regional plan could be quantified to provide a baseline for comparison of alternatives. Detailed quantification of land use and transportation plans could be undertaken.

Concurrently, air quality maintenance policies were suggested to be developed in an attempt to ensure that various alternative plans meet the air quality constraints. These policies could be incorporated into the body of policies and goals,which are a part of the comprehensive plan.

The next step in the implementation plan and enforcement process was to follow and to enforce an administrative procedure developed to ensure an adherence to the policies developed. It was suggested that the state air pollution agencies, the regional planning agencies and local and public agency representatives select the most appropriate method for achieving this procedure. The selected approach was to be presented to the public together with a revised comprehensive plan at public hearings.

It was suggested in the AQMA Plan that emissions allocation appeared to be the best administrative approach for long-term air quality maintenance relative to adequacy and inforceability. Since the administrative structure and procedures required to implement this approach would take considerable time and effort, it was concluded that regional development planning be implemented until the optimal procedure and structure for implementing an emissions allocation approach could be determined and implemented.

It was also suggested than a review of the impact of the then current land use and transportation projects be used as the first step in implementing this regional development planning. In addition, the air pollution agencies and the EWGCC advisory board were told to cooperate to persuade new significant sources of TSP and SO_2 to avoid hotspot areas. If this persuasion failed to obtain the desired results, hotspot regulation and new source review regulations were suggested with strict enforcement to implement recommendations in the plans.

B. DEVELOPMENTS IN ST. LOUIS SINCE THE AQM PLAN

A number of activities have occurred in St. Louis since the AQM Plan was completed in December, 1974. These include:

- The Development of Alternative Transportation Control Strategies
- Inspection/Maintenance (I/M)
- Vapor Recovery
- SIP Regulations

1. Transportation Control Strategies.

In June 1975, the East-West Gateway Coordinating Council agreed to assist the Missouri Department of Natural Resources in the development of a Transportation Control Plan (TCP) for metropolitan St. Louis. The goal of the TCP was to reduce mobile source emissions 20% for carbon monoxide and 65% for hydrocarbons. The main methods proposed to be used to reach these goals were the reduction of areawide vehicle-miles-traveled (VMT), the improvement of traffic flow, and the reduction of emissions from individual vehicles. This work culminated in the development of a document entitled Alternative Transportation Control Strategies, that was published as a technical draft in April, 1976. A summary of the strategies, the percent reduction in mobil source emissions and the approximate cost to implement each strategy is contained in Table III-2. Each of these strategies is discussed below:

a. Inspection/Maintenance

Inspection/maintenance is a control strategy that ensures on-the-road vehicles minimize their emissions by keeping the vehicle property maintained. The two types of tests are idle test (vehicle on idle) and the loaded test (vehicle at simulated road speed using a dynameter). These tests can be conducted by a state-licensed, or state-franchised system. Also, programs can be mandatory or

TABLE III-2
MOBIL SOURCE EMISSIONS REDUCTIONS

STRATEGY	PERCENT REDUCTION	APPROXIMATE COST TO IMPLEMENT
Inspection/Maintenance		
a. State owned Idle	5.0-6.3	$1.50 - 3.00/vehicle 52,000 - 121,000/test facility
Loaded	5.3-7.9	$5.00-8.500/vehicle 72,000 - $137,000/test facility
b. State Licensed Idle	4.2-5.0	$3.00 - 6.00/vehicle 2,000 - 3,500/test facility
Loaded	not applicable	not applicable
c. State Franchised Idle	5.0-6.3	$2.00-4.00/vehicle $52,000 - 121,000/test facility*
Loaded	5.3-7.9	$5.00 - 9.00/vehicle $72,000 - 137,000/test facility*
Parking Management	variable depending on extent and type of controls	Negligible or negative - more productive use of land
Carpooling	7.0	up to $1,000,000 for effective advertising

*Cost borne by contractor and not by state.

SOURCE: Transportation Control Strategies
April/1976

TABLE III-2

EMISSIONS REDUCTIONS CON'T.

STRATEGY	PERCENT REDUCTION	APPROXIMATE COST TO IMPLEMENT
Improved Transit	0.5	$145 million over four years
Reserved Lanes	Local effects* (4.0% in I-70 corridor)	$500,000 - 750,000 for I-70
Signal Synchronization	1.6	Variable depending on type of equipment
Rescheduled Hours	0.5-10 (if matched for carpools first)	negligible

*Presently Lindell-Olive arterial corridor is operating and under surveillance.

voluntary. Expected hydrocarbon reduction estimates range from 4.2% to 7.9% depending upon the implementation method.

In St. Louis, the final inspection/maintenance program has not been resolved and two issues remain: the type of program to be implemented and the geographical area of coverage. It is now believed that an inspection/maintenance program will be implemented for the entire geographic area. However, final plans may change this concept.

b. Parking Management

Parking management is a strategy that attempts to reduce the number of people using the automobile diverting them to a mass transportation system. Conflict arises in areas where parking regulations require a certain minimum in parking areas. In St. Louis the strategy has been suggested to provide a disincentive for the use of low occupancy private autos. The East-West Gateway Coordinating Council is presently completing an inventory of parking demand in critical areas and is evaluating alternative parking control strategies. Final recommendations will be made in cooperation with local officials and the private sector.

c. Reserved Bus Lanes

This strategy is closely related to improved transit and car pooling. It provides for exclusive bus and car pool lanes on major arterials and freeways. Its effect is to speed up travel times thereby providing an incentive for people to use buses or car pools.

In St. Louis it was recommended that four arterial systems be further studied for use as exclusive bus lanes. These four facilities are U.S. 40, I-70, Grand Avenue and Kingsway Boulevard.

d. Improved Transit Service

Better transit service is considered one method of reducing travel. Attracting commuters has been the object of many service improvements made around the country. This is done primarily because these trips are made regularly and are typically longer than other types of trips. Many commuters use transit to get to work because it is convenient and economical. These transit users also reduce congestion on highways and air pollution by using the bus instead of driving themselves. Consequently, mass transit should be considered as having a potential for reducing air pollution within the region.

In St. Louis, a number of improvements have been suggested as a means to improve transit service. These suggestions are listed below along with the potential VMT reduction for each:

Service	No. of Daily Users	Estimated VMT Reduction
Improvements to Existing Service	6,000	60,000
Park & Ride Service	1,700	23,000
New Routes	3,000	30,000
Special Services	1,300	13,000
Off-peak shopper services	200	2,000
Demand-Responsive	600	6,000
	TOTAL	132,000

The overall projected impact of this transit development program for the first year is about 0.8% reduction in total area wide VMT. Similar improvements are being suggested for four subsequent years as part of a five year transit development plan. It has been suggested that when implemented the total program could reduce VMT by attracting 20% of the potential trips now being made.

e. Car Pooling

Car pooling is a strategy that attempts to reduce the VMT by reducing the number of cars on the road. This strategy is currently being used in St. Louis by a few employers. It is dependent upon some kind of incentive to encourage people to form a car pool. High incentives can double or triple the automobile occupancy for work trips.

It has been suggested that car pool programs could be implemented in the St. Louis Region by employers who have a work force of 100 or more. Car pool programs through these employers could eliminate 1.8 million VMT/day. In addition, car pool programs could be developed for educational institutions with 250 or more staff, faculty and students.

f. Signal Synchronization

The St. Louis metropolitan area contains about 1,200 signalized intersections within the urbanized boundaries. Of these, 768 intersections (68% of total) are interconnected to provide about 140 miles of synchronized routes. These signalized intersections are maintained and operated by individual traffic agencies in both states. It is the intent of these agencies to provide uninterrupted traffic flow, minimize congestion, and improve the level of service on the routes under their jurisdiction. The specifications and standards that are to be used in the design and operation of signalized intersections have been established by federal authorities and are contained in the Manual on Uniform Traffic Control Devices.

The majority of signalized intersections within the urbanized boundaries are located on the arterials and CBD streets; some of these signals are interconnected by either pretimed clocks, or some type of physical interconnection. There are signalized intersections divided into about 105 separately controlled interconnected systems which include as few as two (2) intersections or as many as about two hundred (200) intersections (St. Louis central business district system).

In St. Louis it was concluded that a well designed signal synchronization system along the primary arteries offered the greatest opportunity for reducing emissions. The amount of region-wide reduction that could be expected to result from coordinating the traffic signals and thus increasing the operating speeds from principal arteries would be about 2%, and from minor arterials, the expected reduction would be 1%.

g. Rescheduled Hours

Rescheduled hours attempt to relieve congestion during peak traffic times by having staggered work hours, a flex-time system, or a four-day work week. Disadvantages can occur by reducing the number of car pools, therefore, negating any benefit of the strategy.

In St. Louis, it was recommended that further study be given to the four-day work week. It was concluded that the other alternatives did not decrease VMT and that the four-day work week had the possibility of at least decreasing the total number of work trips.

2. Inspection/Maintenance (I/M).

Since the East-West Gateway Coordinating Council published their study "Transportation Control Strategies for the St. Louis Metropolitan Area" which contains an analysis of several variations of an Inspection Maintenance (I/M) program, a consultant, G.C.A. Corporation, Bedford, Massachusetts was retained to perform an indepth cost-effectiveness study on the various alternatives of the TCP for I/M. The consultant was commissioned to collect data and program results from states who have Inspection Maintenance program in existance to determine which combination of test method (loaded or idle) and test financing (vendor or state operated)would be most cost effective. The consultant was further instructed to review Missouri's state automotive safety inspection program to determine possible methods of combining both inspection programs into one program.

Missouri is presently preparing legislation for the creation of an Inspection/Maintenance (I/M) program. The submittal of the legislation will probably coincide with the issuance of a report from G.C.A. summarizing their cost effectiveness analysis. Illinois is in Federal EPA Region #5, whereas Missouri is in EPA Region #7, and subsequently Illinois is not being evaluated for inclusion in the I/M program by the consultant who is being contracted by EPA in Region #5.

3. Vapor Recovery.

On October 11, 1976, the Missouri Air Conservation Commission promulgated a gasoline storage and transfer regulation through the Missouri legislative system. This regulation dealt with gasoline emission limitations from bulk terminals, bulk plants and service stations. From all bulk terminals and bulk plants handling more than 600,000 gal./month, vapor recovery equipment must be installed to limit emissions of hydrocarbons to .5 grams/gal. pumped into the receiving vessel. Facilities handling less than 600,000 gal./month are exempt from the vapor recovery providing they use submerged loading facilities. In transfering gasoline from a delivery vessel to a stationary tank over 2,000 gal., a recovery rate of 90%, must be achieved. For tanks 250 to 2,000 gal. the only reduction procedures to be used are submerged fill aparatus.

4. SIP Regulations.

The Missouri air pollution regulations which are a result of the air pollution analysis performed in the Missouri State Implementation Plan are being modified through recommendations from the engineering section. As was the situation with Regulation XXI (a regulation to control hydrocarbon emissions from gasoline storage facilities) the engineering section recommends new regulations to combat excessive polluting sources which are the promulgated. Revisions to the original SIP Regulations other than Regulation XXI have not been forth coming because of two reasons. The first is a lack of staff in the engineering section. The second is the soon to be issued ammendments to the Clean Air Act. These ammendments should be issued within a few months.

On January 14, 1977, Senator Muskie introduced three bills that would amend the Clean Air Act. These three bills are similar to legislation submitted during the previous year. The contents of the bills deal with such items as; non-degradation, extension of automobile emission standards, cleaning up of deadlines, extensions on a case-by-case basis for industry and for Transportation Control Plans, providing penalties for major non-complying facilities, setting up controls conditions for plant expansions in dirty-air areas and for those converting to coal.

The non-degradation provision would:

a. Apply in areas cleaner than required by federal ambient air quality standards protecting health and welfare;
b. Mandate certain "pristine" or Class I areas;
c. Establish conditions for states to designate remaining clean-air areas as Class I or Class II, permitting moderate growth;
d. Establish for Class I and Class II areas an allowance for increases or increments of ambient levels of sulfur dioxide and total suspended particulates;
e. Direct EPA to study increments for other pollutants and to recommend within one year increments for nitrogen oxides and hydrocarbons;
f. Apply the rules through the state permit process to specific new major industrial sources and other new industrial sources that potentially could emit 100 tons of pollutants per year;
g. Require new major sources to use best available control technology defined on a case-by-case basis as a system of continuous emission controls "taking into account energy, environmental, and economic impacts and other costs";
h. Establish a mechanism enabling the federal land manager, the EPA administrator, or an adjacent state governor to challenge construction of a source that could adversely affect a Class I area.

As Washington contemplates changes in Federal legislation, Missouri is holding public hearings regarding changes in sulfur oxide emission regulations from fuel burning as well as process equipment. Changes in the state regulations will affect Union Electric as well as many other small sources.

C. SUMMARY OF AIR CONTROL STRATEGIES IN ST. LOUIS

The AQMA Plan developed for St. Louis and completed in December, 1975, contained recommended strategies for attainment and maintenance of air quality standards. Unfortunately, most of the strategies contained in the plan were quite general and no quantification of costs was associated with particular elements of the plan. As a result of the plan, further efforts were needed to develop some of the suggested strategies contained in the plan. These strategies are in various phases of development and it cannot be assumed that all or any of the strategies will be implemented. This section will attempt to summize what elements of the AQMA Plan have been or will be implemented. These conclusions are based on discussions with officials from the East-West Gateway Coordinating Council and on documents obtained from various agencies in St. Louis. Although they may not reflect what will actually occur in St. Louis they will be used as the basis for comparison with the open space plan developed in the following Chapter.

The AQMA Plan concluded that the following reductions would be needed by 1975 in order to meet air quality standards:

	NECESSARY EMISSION REDUCTIONS (tons/yr)
TSP	21,662
SO_2	0
CO	135,662
HC	48,507

Based on this analysis, it was concluded that attainment strategies would be needed for TSP, CO and oxidents. In addition, since hotspot location may violate SO_2 standards, an attainment plan would be needed at certain locations.

The following recommendations were included in the AQMA Planas attainment measures for particular pollutants:

TSP - expand the monitoring surveillance programs to accurately trace efforts of the State Implementation Plan controls.

SO_2 - use no new control measures until all SIP regulations are in effect.

CO - induce the use of lighter weighted cars, reduce non-essential travel, improve mass transit, and implement a car pool incentive program. (These strategies plus the Federal Motor Vehicle Emission Control Program should attain CO standard by 1977).

oxidants - apply best available technology for hydrocarbon stationary sources, as well as implement the CO strategies for moble sources.

Once standards are achieved by 1977, the AQMA Plan concluded that the following additional reductions would be needed by 1985 to maintain air quality standards as society continued to change and grow:

	NECESSARY EMISSION REDUCTIONS (tons/yr)
TSP	44,106
SO_2	186,053
CO	0
HC	0

The recommended maintenance strategy for each pollutant was divided into interim and long-term solutions. Each strategy is itemized below:

	Interim Measures	Long-term Maintenance
TSP	Implement hotspot regulations	Long-term comprehensive approach
SO_2	Implement hotspot regulations, burn refuse in power plants, SO_2 reduction at power plants	Long-term comprehensive approach
CO	Indirect source review exclusive bus/car pool lanes	Long-term comprehensive approach
O_x	HC stationary source control	Long-term comprehensive approach

The AQMA Plandid not contain any data on specific estimates of pollutant reduction by strategy. In fact, it can only be assumed that the combination of strategies would maintain air quality standards as no estimate was made of the total reduction expected from all strategies. No definitive time table was suggested for implementation of each strategy. Therefore,it was assumed that the interim measures would produce results until approximately 1985 when a long-term comprehensive plan could be implemented.

In regard to the suggested intermin measures, the following comments are offered. For TSP, no hotspot regulations were enacted since current monitoring data indicates that air quality standards are being maintained. However, projections indicate that future maintenance measures will be needed. For SO_2, no hotspot regulations were enacted. A system is being implemented at Union Electric that will permit burning municipal refuse as a power source. In terms of the SO_2 reduction at three major power plants, emissions are being reduced by lower sulfur fuel. For CO, no indirect source review has been implemented and exclusive bus/car pool lanes are being studied. For O_x, a stationary source control program is being studied. Inspection maintenance has been suggested as implementable by 1982; vapor recovery measures could be implemented by controlling petroleum liquid storage, loading and transfer, degreasing and dry cleaning operations by June 30, 1977, and by controlling automotive painting, metal coating, and other surface coating operations in the early 1980's.

It is also impossible to predict whether any of the transportation control strategies mentioned in Section B of this Chapter will be implemented. For the purposes of this study, it is assumed that such strategies will be enacted to reduce both the CO and O_x problems in St. Louis. The effect of the motor vehicle emission reductions at the national level will have a major effect on the reduction of these pollutants.

Based on the above discussion, it is assumed that air quality standards will be attained in St. Louis by about 1978 using SIP enforcement regulations and a Transportation Control Plan. After the standards are attained, the interim maintenance measures contained in the AQM Plan will maintain the standards until about 1985 when a long-term maintenance plan can be enacted.

IV. ANALYSIS OF OPEN SPACE AS A CONTROL STRATEGY TO MEET THE AIR QUALITY STANDARDS

A. METHODOLOGY AND OBJECTIVES

The main purpose of Volume III of this study is to examine the effectiveness of using open space an an air resource measure and specifically to determine if it can be used as an air control strategy as one part of an example air quality maintenance plan. As discussed in earlier sections, St. Louis was chosen as the site of a demonstration plan. Chapter II of this Volume reviewed the AQMA Plan previously developed for St. Louis as well as developments in St. Louis since the completion of the plan. In Volume I of this study, sink factors for various pollutants by vegetative species were determined and Volume II contained various design schemes for regional open space systems as well as particular buffer strips. The remainder of this section will use the analytical information contained in Volumes I & II and apply it to St. Louis in order to develop an open space plan that could be used as a substitute or in conjunction with the AQMA Plan.

The methodology used in developing this open space plan was to first determine what emission reductions would be needed to maintain air quality standards in the AQMA after the standards are attained. The reductions were calculated on a pollutant by pollutant basis. The second step was to determine what amount of open space would be needed to absorb these same amounts of pollutants. It was decided to develop a hypothetical vegetative unit consisting of one hectare of typical plants that are indigenous to the area and that could maximize pollutant reductions. The"sink capacity" of this hypothetical hectare was calculated. The only remaining problem was then to determine the location and the number of these plantings. The thirdstep was to determine the availability of land in the St. Louis area that could be used as open space. This involved reviewing both the existing and proposed land use plans in order to determine what areas could be used as open space. Finally, the hypothetical plantings were super-imposed on the potential open space areas using the design concepts developed in Volume II. Each of these steps are explained in more detail in the remainder of this section.

B. DEVELOPMENT OF OPEN SPACE PLANS

1. Land Availability.

The existing uses of land in the St. Louis metropolitan area and its surrounding environs generally determines the final configuration of the open space plan proposed in this report. St. Louis has developed in a manner similar to that experienced by other cities. The confluence of the Mississippi and Missouri Rivers provided a logical location for settlement of the region and later attract additional people, commercial and industrial activities. The core city grew outward along radial transportation corridors with the Mississippi forming a natural barrior to the growth.

An examination was made of the existing land use of the study area and also the planning objectives of the East-West Gateway Coordinating Council. The Coordinating Council has performed a comprehensive inventory of its natural, social and economic conditions in order to prepare a proposed regional land use plan for 1995. These existing conditions, goals and objectives, determined how we would select land to be used for open space.

As part of their process, the council inventoried undeveloped land which included:

1. Forest Cover.
2. Flood Prone Areas.
3. Steep Slope Areas (16% or greater).
4. Agricultural and Vacant Lands.

It was felt that forested land should not be considered for the open space plan. Those areas are already operating as sinks for pollutants, and although they could be made to operate more efficiently (through the installation of thermal chimneys, expansion and diversification of forest edge and establishing multi-layered stratification - Section II-C, Volume II) the net benefit would be minimal compared to planting vacant land.

The most obvious choice of land utilized in the open space plan was that identified as agricultural and vacant lands. This is land which is either in active agricultural use or is vacant and not being utilized as commercial, industrial, utility or residential land. These are the lands which will receive increased development pressures, but which also have environmental value.

Of the vacant land inventoried, a further survey was performed in order to identify land which could be more advantageously used in the open space plan.

This resulted in a differentiation between non-steep slopes (less than 16% grade) and steep slopes (16% or greater grade). The steep slopes can best be placed into a planted state for a variety of reasons. These areas are difficult to build upon and are usually characterized by surface bedrock, and they are subject to erosion if not planted. These lands are also less desirable for development because of the site work required and other associated problems. As such, these lands are identified in Figure IV-1 Synthesis I: Available Land For Planting.

The other type of vacant land that required evaluation was the flood prone areas. As pointed out in the 1995 Regional Land Use for metropolitan St. Louis, few metropolitan regions in the world contain as much flood prone land in such close proximity to the metropolitan core as the St. Louis area. Approximately 20% of the region's surface area is flood plain, This figure would be even higher if one limited consideration to the highly urbanized portion of the region within about a 20 mile radius of the core. For a variety of reasons, including environmental conservation cost to the taxpayer, and personal safety, flood plain development has been slow. The Land Use Plan recognizes the fact that flood plains can exhibit an unusually high level of environmental sensitivity, and that development on them should be carefully considered. But the plan also recognizes that use of the flood plain for development cannot be prohibited.

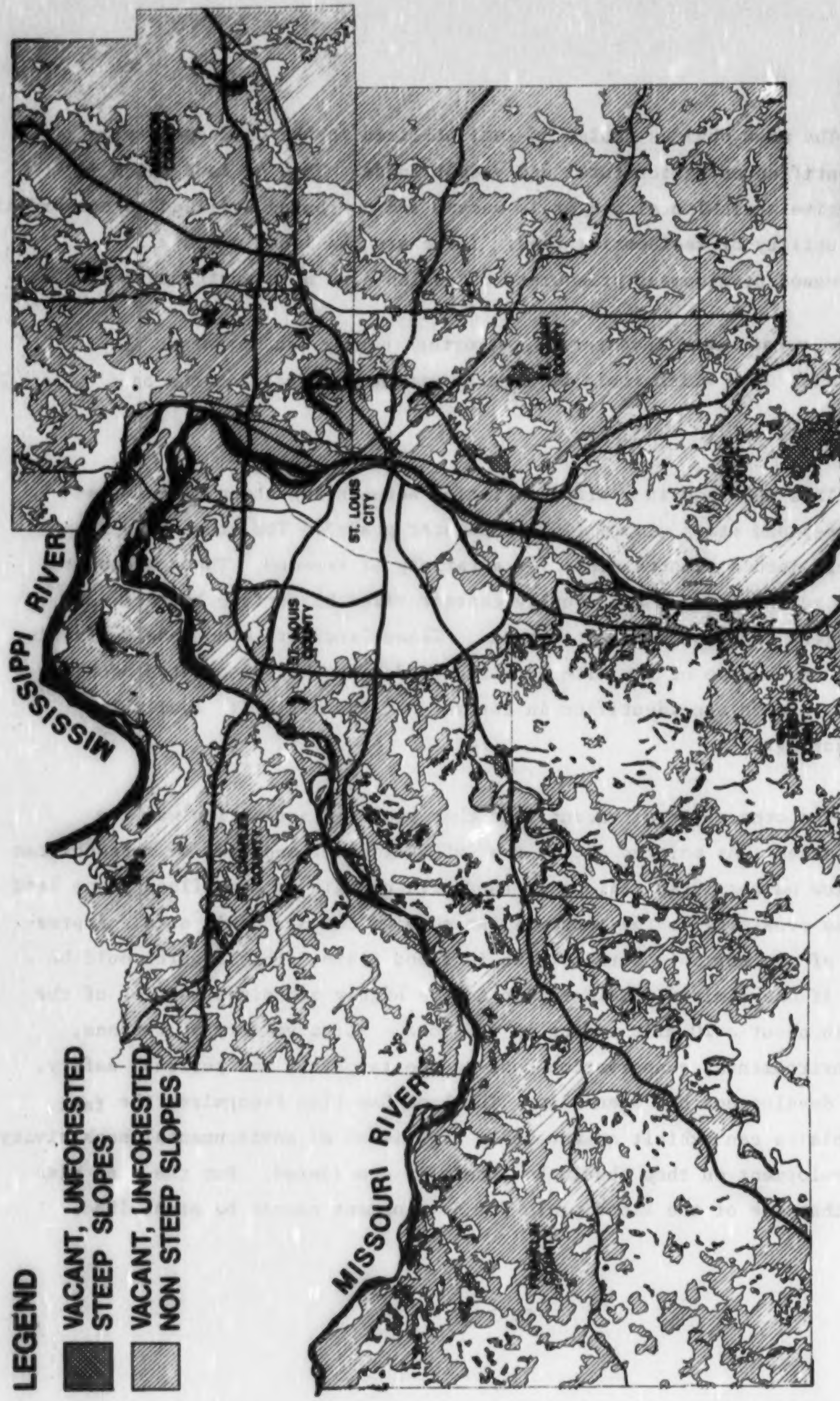
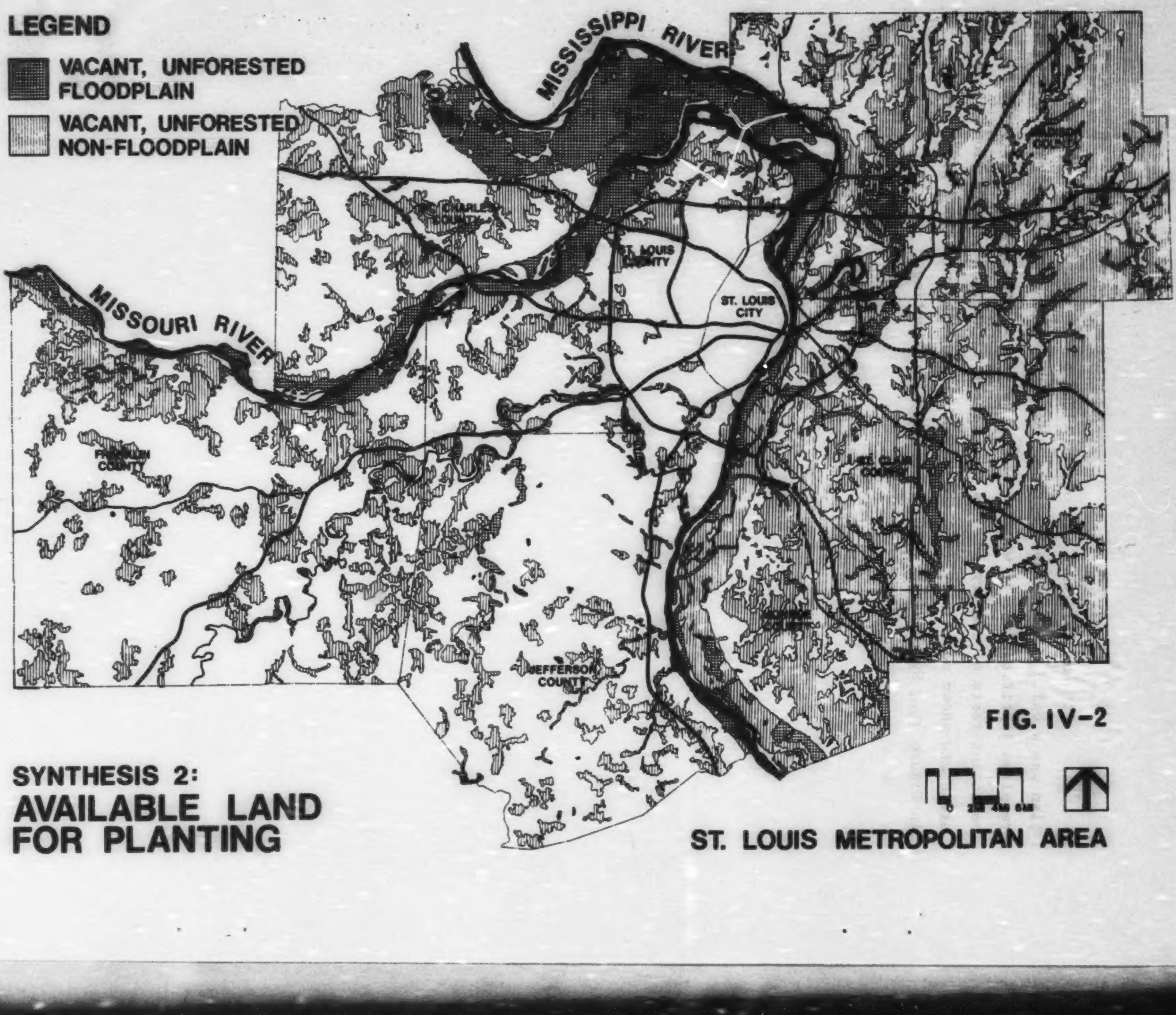

LEGEND
VACANT, UNFORESTED STEEP SLOPES
VACANT, UNFORESTED NON STEEP SLOPES
MISSISSIPPI RIVER
MISSOURI RIVER
ST. LOUIS CITY
ST. LOUIS COUNTY

FIG. IV-1

SYNTHESIS 1:
AVAILABLE LAND FOR PLANTING

ST. LOUIS METROPOLITAN AREA

It was felt that use of the flood plain areas for the open space plan was a valid and desirable option. As any development within the flood plain requires justification, it was felt that its use as open space would serve the basic interests of the region. As such, these vacant, unforested flood plain areas are shown separately from the vacant, unforested non-flood plain areas in Figure IV-2 Synthesis 2: Available Land For Planting.


LEGEND
▦ VACANT, UNFORESTED FLOODPLAIN
▤ VACANT, UNFORESTED NON-FLOODPLAIN
MISSISSIPPI RIVER
MISSOURI RIVER
ST. CHARLES COUNTY
ST. LOUIS COUNTY
ST. LOUIS CITY
FRANKLIN COUNTY
JEFFERSON COUNTY
ST. CLAIR COUNTY
COUNTY
0 2M 4M 6M

SYNTHESIS 2:
AVAILABLE LAND FOR PLANTING

FIG. IV-2

ST. LOUIS METROPOLITAN AREA

2. Determining the Pollution Reductions Needed to Maintain Air Quality Standards.

As stated in Chapter III, the AQMA Plan contained data on emission projections for 1975, 1980 and 1985. This data is reproduced in Figure IV-3 In addition to the quantity of pollution being generated, the levels representing the National Primary Ambient Air Quality Standards are displayed by the dashed line. It was not clear how these levels, representing the National Primary Ambient Air Quality Standard, were determined. It can only be assumed that they were obtained through atmospheric modeling.

In order to determine the quantity of pollution reduction needed to maintain air quality standards, the difference between the top of each bar and the dashed line in Figure IV-3 was reviewed. The results of this analysis is summarized below:

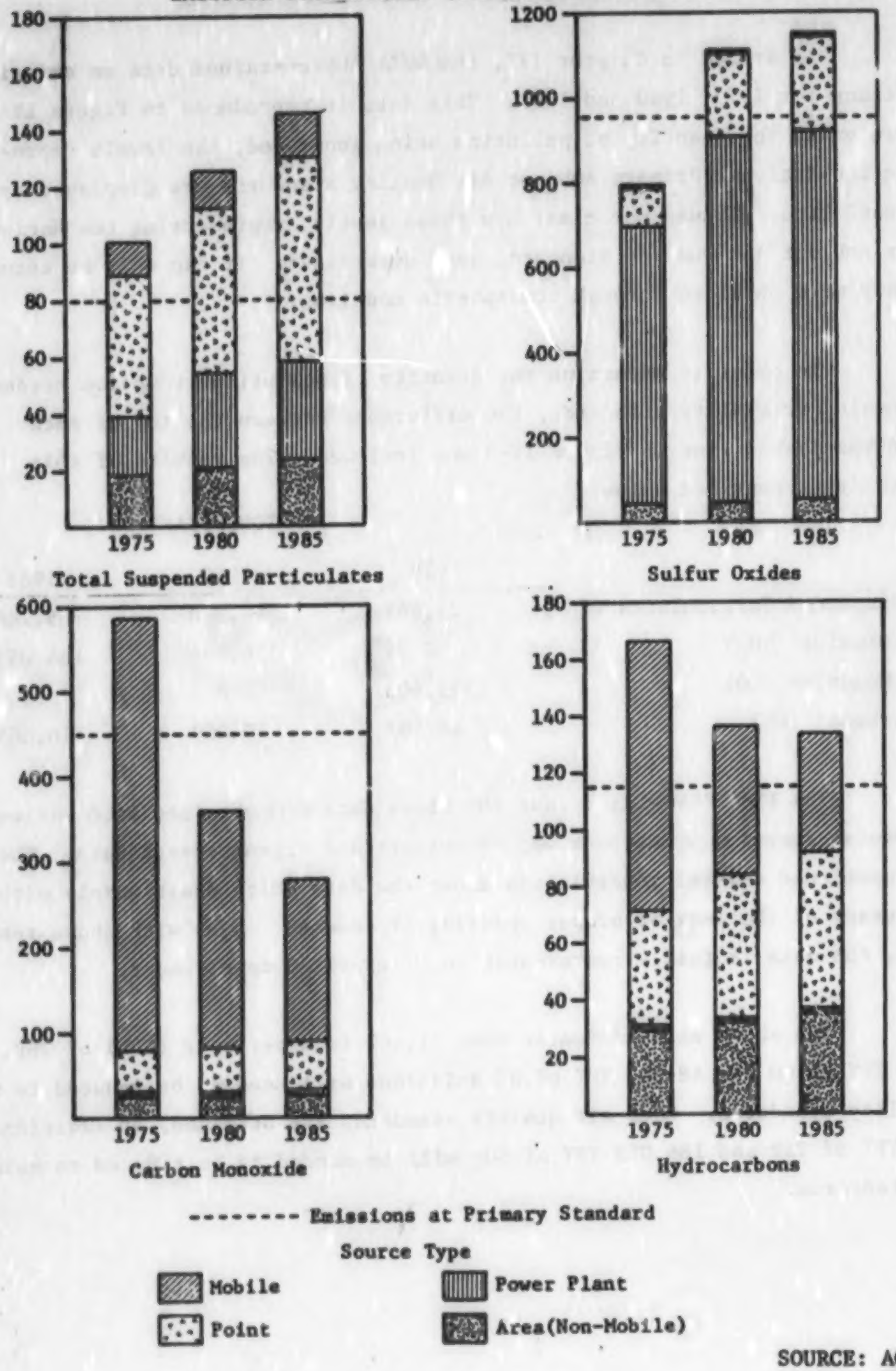
	TONS/YEAR		
	1975	1980	1985
Total Suspended Particulates (TSP)	21,662	46,290	65,768
Sulfur Dioxide (SO_2)	0	156,884	186,053
Carbon Monoxide (CO)	135,403	0	0
Hydrocarbons (HC)	48,507	19,009	16,085

The AQMA Plan stated that the above data were obtained from various governmental agencies whose task was to collect and organize such data. The report mentioned several reservations about the data which dealt mainly with the accuracy of the lack of proper updating procedures. Even with these reservations, the data is fairly representative of expected development.

The above data indicates that 21,662 tons per year (TPY) of TSP, 135,043 TPY of CO and 48,507 TPY of HC emissions will need to be reduced to attain air quality standards. Once air quality standards are attained, an additional 44,106 TPY of TSP and 186,053 TPY of SO_2 will be needed to be reduced to maintain these standards.

FIGURE IV-3

ST. LOUIS AQMA
EMISSION PROJECTIONS (Tons/Year X 10^3)



SOURCE: AQMSA St. Louis
EPA-450/3-74-052
December 1974

The analysis performed in the AQMA Plan indicates that after 1975, CO will not be a problem. This reflects the reductions in emissions from the Federal Motor Vehicle Emission Program and the implementing of a TCP. The same conclusion can be drawn concerning hydrocarbons. If a TCP is implemented, then both the CO and HC (oxidant) standards would be attained and the emission reductions from the Federal Motor Vehicle Emission Program would prohibit violations of these standards in the future.

It is not the purpose of this project to question the validity of either these projections or whether the emission reductions projected in the Federal Motor Vehicle Emission Program will actually occur. We have assumed that a TCP will be implemented in St. Louis and that the emission reductions will occur at the source (automobile) as projected.

3. The Hectare Vegetative Unit (Hypothetical).

A one hectare forested unit of open space was developed in order to estimate the quanitiy of certain air pollutants removed by the natural elements of such a standardized and unitized forest. Five tree species are recommended for planting in this model forest including red oak (*Quercus robur*), Norway maple (*Acer platanoides*), linden (*Tilia cordata*), poplar (*Populus tremula*), birch (*Betula verrucosa*)and Eastern white pine (*Pinus strobus*). Even though the St. Louis region is outside the main biogeographic range of *Pinus strobus*, the tree was used in the model, as opposed to Scotch pine (*Pinus sylvestris*) which thrives in St. Louis. The data relating to white pine was more readily available and more comprehensive. It was assumed that the calculations involving white pine would adequately define the conditions for Scotch pine.

This hypothetical hectare consists of two subsections in which the deciduous trees are planted in one subsection and the coniferous trees are planted in the other. The dimensions and arrangement of both subsections are shown in Figures IV-4 and IV-5.

The deciduous subsection is comprised of two adjacent sides of the hectare planted as a strip twenty meters wide. Ideally, at least one side of this L-shaped area would be placed windward relative to the prevailing wind. One reason for this is that a substantial amount of airborne contaminants removal will be effected by the deciduous trees thus protecting the more sensitive conifers. Conifers are apparently more sensitive to air pollutants than are most deciduous trees perhaps because foliage of the conifers is replaced more slowly than that of deciduous trees. This results in greater long-term exposure of the conifers to concentrations of pollutants. Even though conifers are more susceptible to the adverse effects of airborne contaminates than are most deciduous tree species, conifers were nonetheless included in the hypothetical forest hectare, accounting for the majority of the trees (700 out of 1044). Conifers are used to provide continuous air filtering action. Since the coniferous trees planted in the model hectare retain their needles throughout the year, the quantities of pollutants absorbed or adsorbed by the coniferous foliage does not vary according to seasonal changes. Also, conifers possess a high surface area to volume ratio which seems to promote the filtration of air pollutants. Further discussion concerning mixed plantings of deciduous and coniferous species may be found in Volume II on page II-47.

The determination of an appropriate width for the deciduous section of the model forest was based on the data published by Warren (1973). He stated that the initial 65 to 85 feet from the edge of a forest can reduce the concentration of particulates by as much as 50%. Since the deciduous trees of the hectare are planted in an area twenty meters (approximately 65 feet) from two adjacent boundaries of the hectare, these trees compose more than half of the edge of the hypothetical forest. The effectiveness of capturing particulates by the deciduous trees may be comparable to that reported by Warren. In fact, the removal rate of airborne particulates by the deciduous trees may be greater since the deciduous area may be characterized by a relatively high diversity and moderate to high density of the tree species.

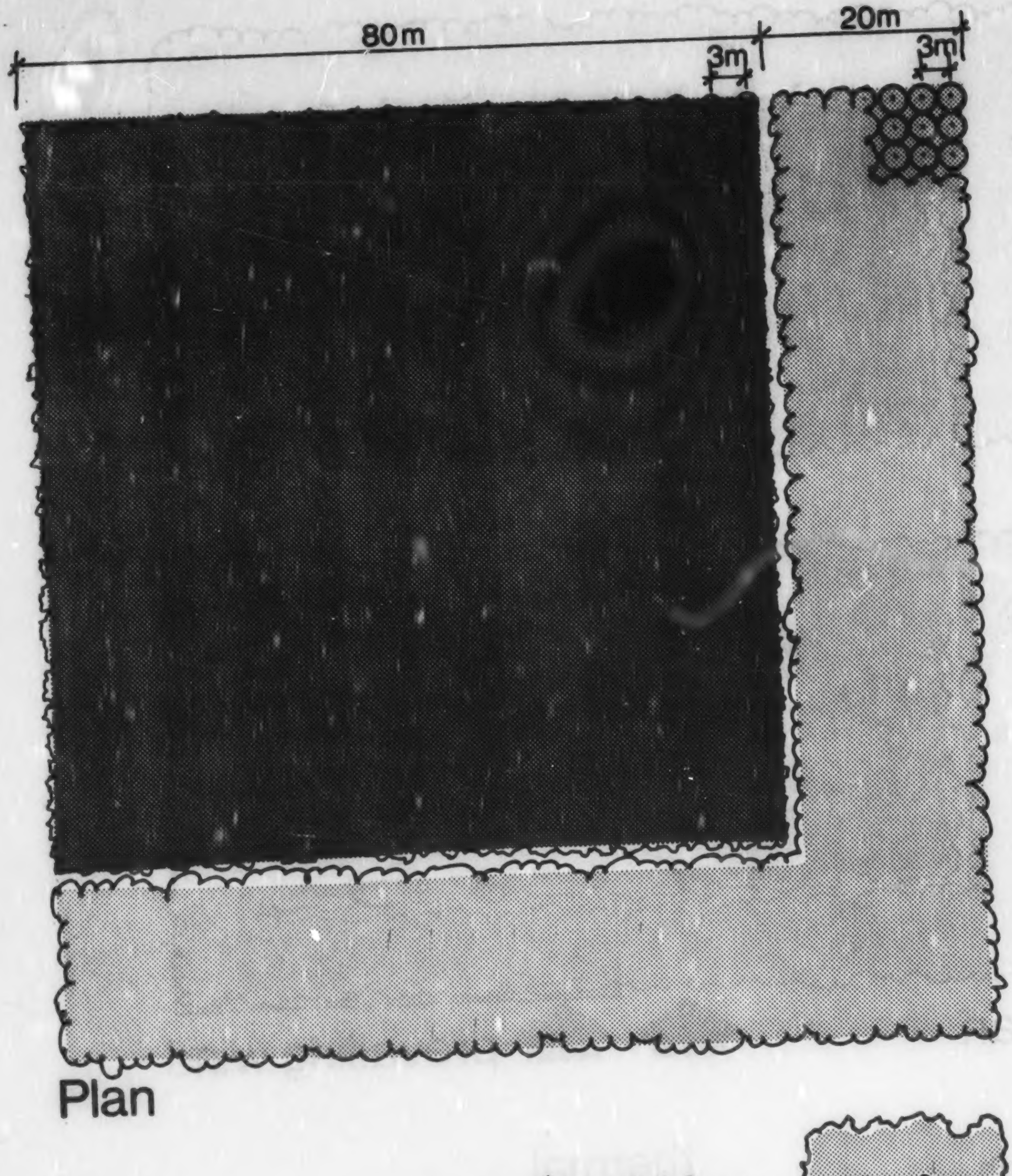

80m
20m
3m
3m
Plan
Section

FIG. IV-4

VEGETATIVE UNIT 1 hectare

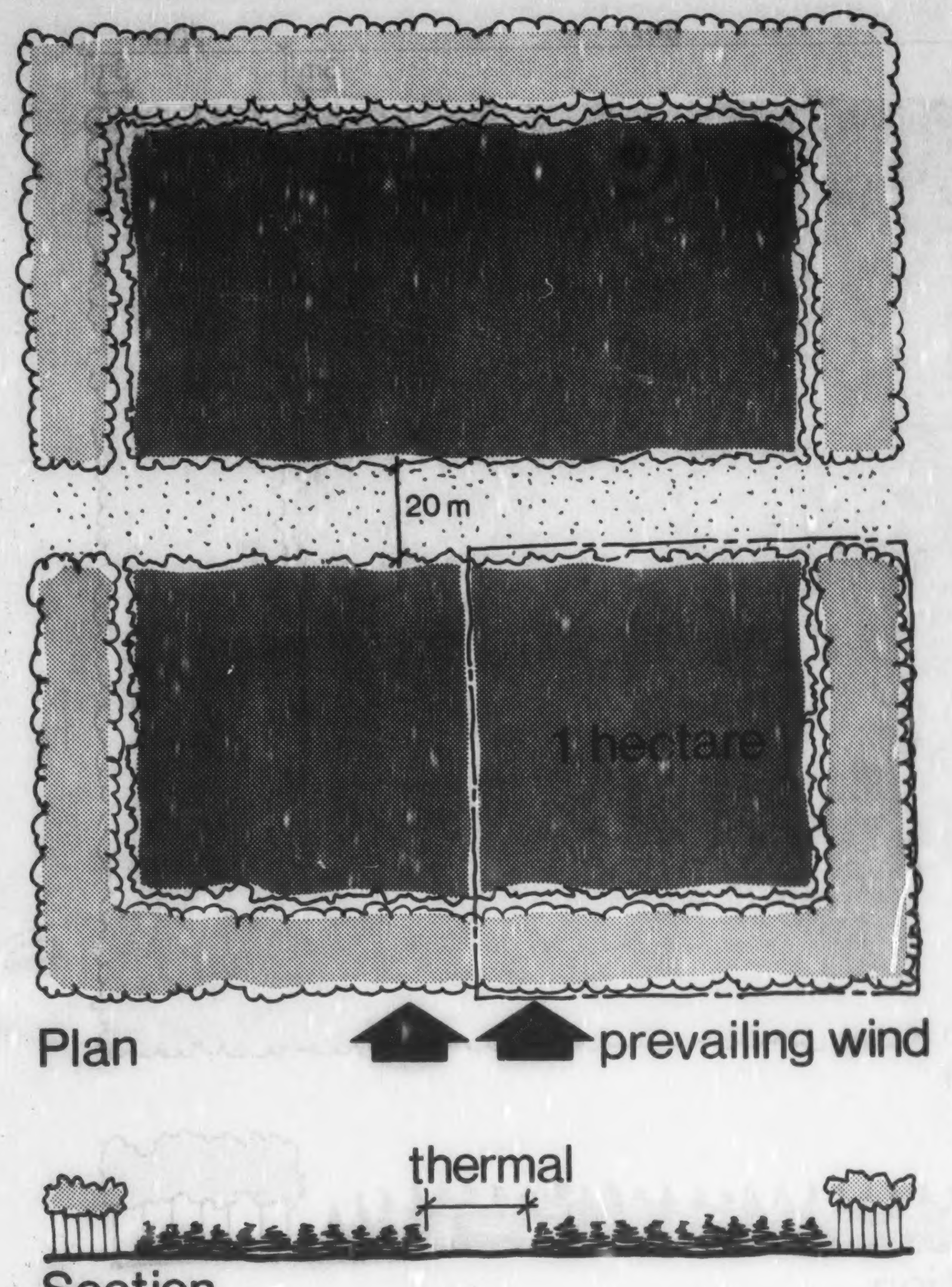

20 m
1 hectare
Plan
prevailing wind
thermal
Section

FIG. IV-5

4 HECTARE GROUPING

As was mentioned previously, five deciduous tree species were chosen to be used in the hypothetical hectare. It was then calculated how many representatives from each tree species were needed to produce a continuous canopy five years after planting.* It was found that 344 three year old deciduous trees (2 to 2½ inch calipers) should be planted in the hypothetical hectare. Each tree should be spaced three meters apart so that when the trees are eight-years-old or five-years-old after planting, the diameter of the individual canopies would be approximately 3m apart. When the trees are eight years old (five years after planting) the diameter of the individual canopies will be approximately 3m and each tree canopy would touch the adjacent canopies. The 344 deciduous tree would eventually form a dense forest with individual tree canopies that would increasingly overlap as the forest aged; thereby enhancing the amount of vegetative surface area. That increase is directly related to an increased sink capacity of the area.

Some factors which influence the efficiency of the vegetation in removing airborne pollutants include placement with respect to prevailing winds, the width, density, and the diversity of the deciduous area of the hypothetical hectare. If a high sink capacity is present in the deciduous section, it is more likely that the more sensitive, continuously "filtering", conifers would be relatively protected from the harmful effects of air pollutants.

Table VI-9 in Volume II shows the data concerning the height, diameter of the canopy, canopy area, and estimated plant surface area, of each tree species five years after being planted in the hypothetical hectare. Discussion on how the estimated plant surface area of each tree species was obtained may be found in Volume II, Section III-D and is further detailed in Appendix C of that Volume.

The total estimated vegetative surface area in the model hectare is $15.0 \times 10^3 m^2$. Table IV-1 shows the number of trees of each species planted in the hypothetical forest and the estimated surface area of those trees.

---

*Since 1985 was chosen as the year of reference and it was assumed that an open space plan could not be implemented until 1980, five (5) years was selected.

The exposed soil area of the hypothetical hectare was determined by subtracting the total ground area covered by 1044 tree trunks from the total ground area of the hectare. The diameter of all six tree species were estimated to be six inches (0.15m) five years after planting.

a. Calculation of ground area covered by one tree trunk:

Radius of trunk = 0.075m
Ground area = πr^2 = $0.02m^2$/tree trunk

b. Calculation of total ground area covered by 1044 tree trunks:

Total ground area = ($0.02m^2$/tree trunk) (1044 tree trunks) = $20.9m^2$

c. Total ground area of a hectare = $10{,}000m^2$

d. Calculation of soil area not covered by tree trunks in the model hectare:

Soil area = $10{,}000m^2 - 20.9m^2 = 9.98 \times 10^3 m^2$

Once both the total vegetative surface area and the total exposed soil surface area of the hypothetical hectare were determined, the weighted sink factors were used to estimate the amount of specific pollutants removed from the air by the natural elements of that hectare. Details of this procedure may be found in Chapter III-D of Volume II. In addition, Table III-4 of Volume II displays the weighted sink factors utilized to determine the amount of pollutants absorbed by the hypothetical hectare. Table IV-2 of this Volume shows the estimated amount, in tons/year, of sulfur dioxide, particulates, carbon monoxide, nitrogen oxides, ozone, and PAN removed by the vegetation and soil of the standardized forest.

TABLE IV-1

TOTAL VEGETATIVE SURFACE AREA IN ONE MODEL HECTARE

69 Maple	2.54 x $10^3 m^2$
69 Oak	2.50 x $10^3 m^2$
69 Poplar	3.63 x $10^3 m^2$
68 Linden	1.56 x $10^3 m^2$
69 Birch	1.88 x $10^3 m^2$
700 Pine	2.90 x $10^3 m^2$
TOTAL	15.0 x $10^3 m^2$

TABLE IV-2

THE AMOUNT OF POLLUTANTS ABSORBED BY THE MODEL HECTARE

SO_2	748 TPY
Particulates*	0.36 TPY*
CO	2.2 TPY
Nitrogen oxides	0.35 TPY
Ozone	9.64 x 10^4 TPY
PAN	0.17 TPY

*The weighted sink factor for particulate removal by average soil could not be determined due to insufficient data, therefore, the above calculation represents only the weighted sink factor attributed to vegetation. An extensive literature search was conducted to extract data necessary for developing the Tables of sink and emission factors presented in Volume I. A discussion of the limitations in the information can be found in Section III of Volume I.

4. Development of Open Space Plans.

a. Optional Plans for TSP

Knowing how much pollution must be removed, the total available area for plantings, and the pollution sink factors of the vegetation, the remaining step is to determine the total amount of open space needed to maintain air quality standards for each pollutant. This leads to a plan for the location of open space in the region.

Examining the amount of pollutants absorbed by the model hectare, Table IV-2 , and comparing it with the amount of pollutant reduction needed, it was concluded that the greatest amount of open space will be needed to absorb TSP. Therefore, it was initially decided to attempt to develop an open space plan for this pollutant. The next decision was to determine how much open space was needed and where it should be located.

The atmospheric loading of particulate air pollution contaminants is shown in Figure IV-6 for 1985. This configuration projects the growth of TSP after air quality standards are achieved. It is clear that there are two hotspots that exceed the NAAQS of 75 $\mu g/m^3$. In the development of the open space plan for TSP, three separate considerations were analyzed:

(1) How much open space is needed to regionally accomodate the particulate emissions that cause the NAAQS to be violated?

(2) Is there enough open space directly beneath the isopleths above the NAAQS (75 $\mu g/m^3$) to absorb enough pollutants to achieve standards?

(3) Is there enough open space directly beneath the isopleths for the entire hotspot area (40$\mu g/m^3$) to absorb all the pollution emitted within those areas?

AIR QUALITY
CONCENTRATIONS
IN micrograms/m³

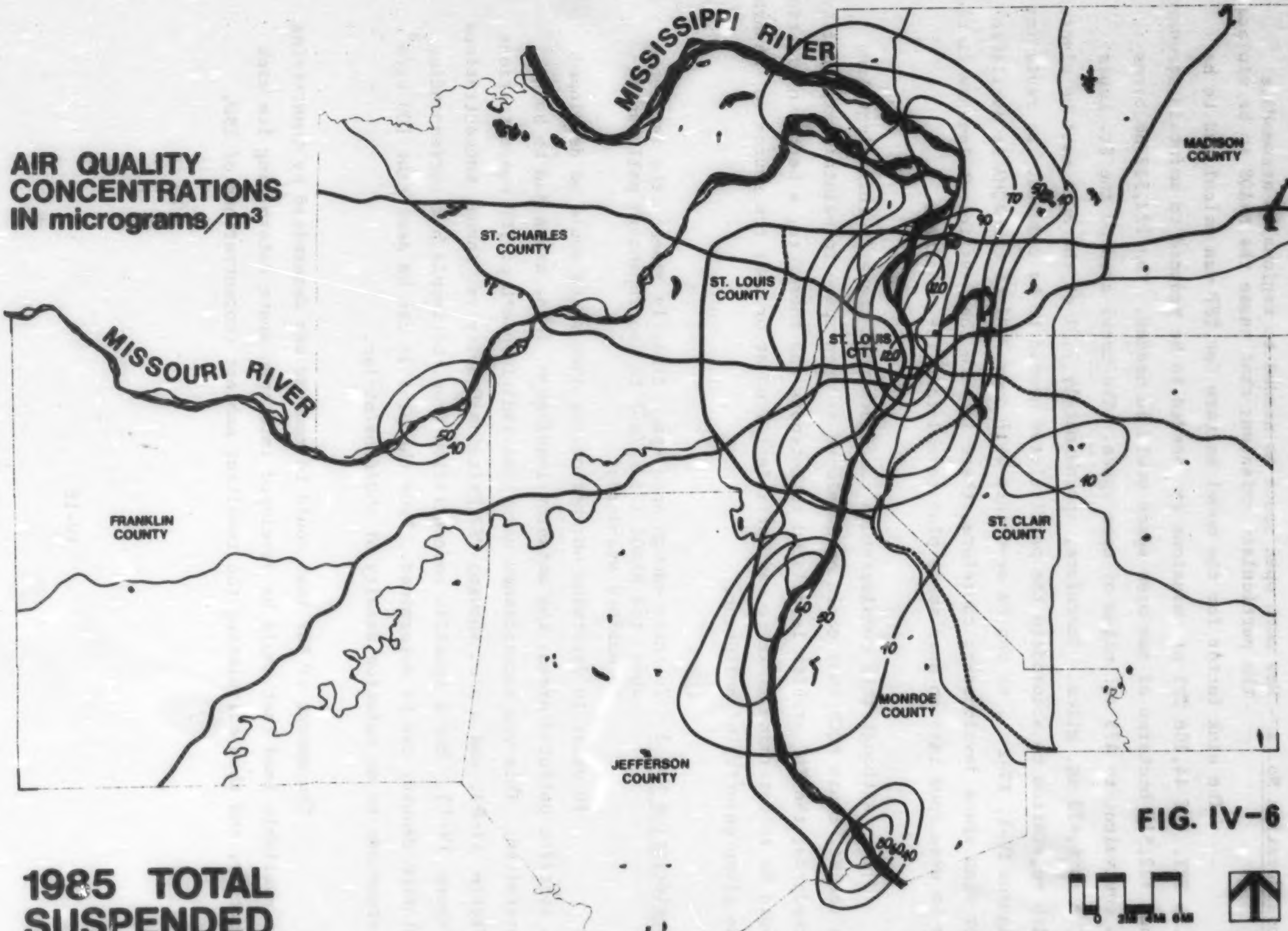

MISSISSIPPI RIVER
MISSOURI RIVER
MADISON COUNTY
ST. CHARLES COUNTY
ST. LOUIS COUNTY
ST. LOUIS CITY
ST. CLAIR COUNTY
FRANKLIN COUNTY
JEFFERSON COUNTY
MONROE COUNTY
70
50
40
90
120
120
50
10
10
40
50
10
80
60
40
0

FIG. IV-6

1985 TOTAL SUSPENDED PARTICULATES

ST. LOUIS METROPOLITAN AREA

Consideration No. 1 - How much open space is needed to regionally accomodate the particulate emissions that cause the NAAQS to be violated?

The sink factor for the model hectare for TSP was calculated to be 0.36 TPY. If 44,106 TPY of emissions are needed to be reduced to maintain standards, then 122,517 hectares of new open space would be needed. The 122,517 hectares is equivalent to 473 sq. miles of open space. The total area of the St. Louis AQMA is 6,472 sq. miles. Therefore, approximately 7.3% of the AQMA must be planted with vegetation to accomodate the particulates needed to be reduced. By reviewing Figures IV-1, IV-2 , it can be seen that well over 7.3% of the AQMA is available for open space development; therefore, there is more than sufficient land available to be developed into an open space plan to maintain TSP standards.

Although this consideration concludes that there is sufficient land in the St. Louis AQCR that could be developed as open space to maintain air quality standards; the TSP problem is related to hotspots and therefore, a better evaluation would be to determine if there was sufficient land at or near the source to absorb the given quantity of pollutant.

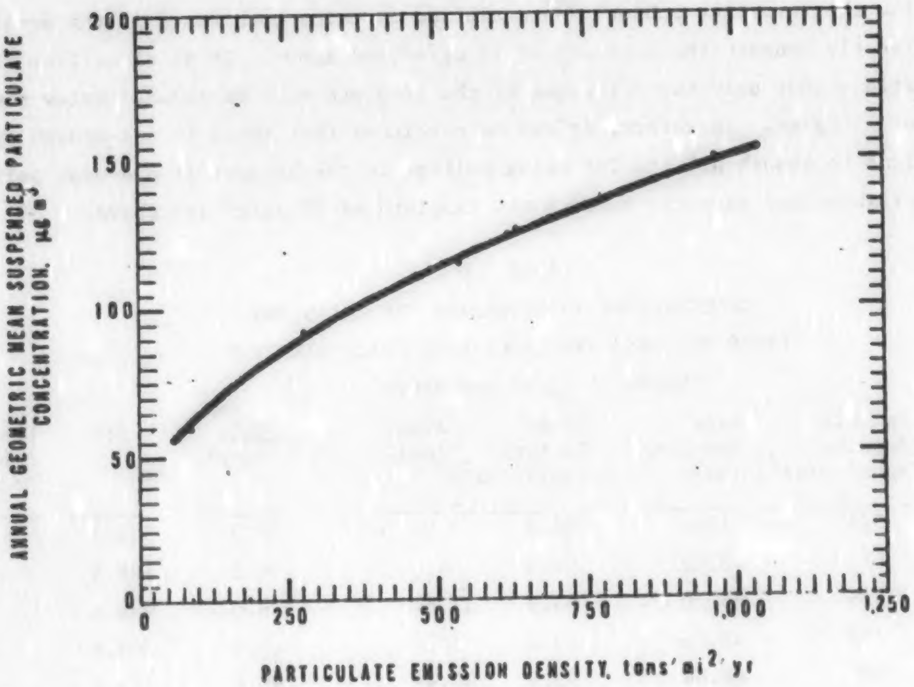
Consideration No. 2 - Is there enough open space directly beneath the isopleths above the NAAQS (75 $\mu g/m^3$) to abosrb enough pollutants to achieve standards?

In order to determine whether or not open space could be developed in specific polluted areas, the emission loadings of these areas had to be determined. This was accumplished using the 1985 isopleth of TSP concentrations (Figure IV-6), and a plot showing TSP Emission Density vs. Annual Concentrations (Figure IV-7). For a specific concentration from the isopleth a corresponding emission density can be determined. From the plot it can be seen that 100 $\mu g/m^3$ corresponds to an emission density of 350/tons/mi^2/yr.

The amount of TSP that could be removed was determined by quantifying the available land that could be developed into open space, determining its sink capacity, and then calculating the resultant ambient concentrations of TSP.

FIGURE IV-7

TOTAL SUSPENDED PARTICULATES
EMISSION DENSITY VS. ANNUAL CONCENTRATIONS*



---

*U.S. Department H.E.W., Interstate Air Pollution Study Pollution Phase II Project Report, December 1966.

The amount of TSP absorbed by a given area of vegetation (Aveg) and the resultant ambient concentration was calculated using the following formulas:

Pollution Collected by Vegetation (P_v) = Aveg. x Sink Factor (S_f) (1)

Resultant Emission Density (E_{pn}) = Existing Emission Density (E_{po}) x Area (2)

$$E_{pn} = E_{po} - \frac{SfAv}{Aispl} \qquad (3)$$

Table IV-3 contains a summary of the calculations performed to determine the resultant ambient concentration by using open space in the available land directly beneath the isopleth of 75 $\mu g/m^3$ and above. It is clear from the calculations that only two (2) areas of the isopleth will be reduced below the NAAQS of 75 $\mu g/m^3$. Therefore, it can be concluded that there is not enough open space land to absorb all the TSP being emitted in the hotspot if one uses only the available land directly beneath the isopleth of 75 $\mu g/m^3$ and above.

TABLE IV-3
CALCULATIONS TO DETERMINE TSP EMISSIONS TAKEN UP USING AVAILABLE OPEN SPACE DIRECTLY BENEATH 75 $\mu g/m^3$ AND ABOVE

	Ambient Concentrations ($\mu g/m^3$)	Emission Density (tons/yr/mi^2)	Area Isopleth (mi^2)	Sink Factors (tons/yr/mi^2)	Aveg (mi)^2	$\frac{StAv}{Aispl}$	Epn	Resultant Ambient ($\mu g/m^3$) Concentrations
** AREA (2)	120	575	12.1	93.3	7.04	54.3	520.7	115
	120	575	8.02	93.3	4.0	46.5	528.5	117
	115	525	35.26	93.3	17.64	46.6	478.4	112
	100	355	42.24	93.3	20.4	45.1	309.9	92
	80	200	86.84	93.3	42.44	45.6	154.4	72
*AREA (1)	80	200	8.56	93.3	3.84	41.8	158.2	72

*AREA 1 is the major hotspot area on Figure IV-6. It includes the area from 40$\mu g/m^3$ to 120$\mu g/m^3$.

**AREA 2 is the minor hotspot area on Figure IV-6 which is located south of the major area. It includes the area from 40$\mu g/m^3$ to 80 $\mu g/m^3$.

Consideration No. 3 - Is there enough open space directly beneath the isopleths for the entire hotspot areas($40\mu g/m^3$) to absorb all the pollution emitted within these areas.

The final consideration is the most realistic assumption to develop an open space plan for TSP. The first consideration concluded that within the entire regional area there is more than sufficient land that could be developed into an open space plan to absorb TSP. However, it is unrealistic to assume that by simply developing open space throughout the AQMA it will produce an ambient concentration of TSP below standards. The second consideration concluded that there was not enough land that could be developed into open space directly adjacent to the hotspot locations to reduce the ambient TSP concentrations below standards. This consideration is also unrealistic because it does not take into account the distribution of TSP pollutants by meteorlogical conditions in the area's immediately surrounding environs. The final consideration will then examine the feasibility of using open space to absorb TSP pollutants in the normally polluted area near the hotspots. The assumption in this final analysis is that some of the pollutants generated by the sources in the hotspot will drift downwind and be taken up by open space within a short distance.

A similar analysis was performed for this consideration as was done for the second case. In this consideration the area used included all the available open space corresponding to the 1985 isopleths of 40 g/m^3 and above. This area was assumed to be influenced by the point sources. Again, the first step was to overlay the isopleth map (Figure IV-6) on the land availability maps (Figure IV-1 and IV-2) and then calculate the amount of land available for open space development within these areas. The plot of ambient concentration vs. emission density (Figure IV-7) was then used to determine the emissions in the area of the particular isopleth. Using sink factors and the area of the vegetation the emissions absorbed in each isopleth were then calculated. These procedures are illustrated in Table IV-4. This analysis concludes that there is sufficient land available for open space development to absorb 38,764 tons/year of TSP in the two areas used in the analysis. Using the predictions of the AQMA Plan, 44,162 tons/year of TSP was needed to be reduced by 1985 in order to maintain standards. The sink factor developed for TSP only considered the vegetative unit as a potential for absorbing TSP

TABLE IV-4

CALCULATIONS TO DETERMINE TSP EMISSIONS TAKEN UP USING AVAILABLE OPEN SPACE DIRECTLY BENEATH 40 $\mu g/m^3$ AND ABOVE

	Ambient Concentrations $\mu g/m^3$	**Emission Density (Tons/yr/mi^2)**	**Area Isopleth (mi^2)**	**Emissions in Area (Tons/yr)**	**Sink Factor (Tons/yr/mi^2)**	**Area for Vegetation (mi^2)**	**Emission Taken up (Tons/yr)**
AREA (1)	120	575	12.1	6,957	93.3	7.04	656.8
	120	575	8.02	4,611	93.3	4.0	373.2
	115	525	35.26	18,511	93.3	17.64	1,645.8
	100	355	42.24	14,995	93.3	20.4	1,903.3
	80	200	86.84	17,368	93.3	42.44	3,959.6
	60	75	145.88	10,941	93.3	311.96	29,105.8
	45	50	343.12	17.156	93.3		
	55	50	56.64	2,832	93.3		
	60	75	21.28	1,596	93.3		
				94,967			37,644.5
AREA (2)	80	200	8.56	1,712	93.3	3,84	358.3
	60	150	17.68	2,652	93.3	2.08	194.1
	40	50	20.00	1,000	93.3	6.08	567.3
				5,364			1,119.7

pollutants. Since the soil also acts as a sink, but was unquantifiable, it can be concluded that additional TSP pollutants can be absorbed by the open space plan which were not included in the calculations. Therefore, it has been concluded that there is sufficient land available for open space development in the hotspot area to absorb enough TSP pollutants to maintain air quality standards.

b. Final Open Space Plan For TSP

Based on the three considerations in Section III,4.a., it was decided that the most realistic and effective open space plan for TSP would be to use all the available land in the area directly beneath the isopleth of $40 \mu g/m^3$ and above. The total emissions adsorbed/absorbed in the two areas analyzed in Table IV-4 was equal to 38764.2 tons/yr. (37644.5 tons/yr. + 1119.7 tons/yr.) including flood plain. This represents approximately 86% of the total emissions needed to be reduced to maintain the air quality standard for TSP. It should also be pointed out that the sink factor for the hypothetical vegetative unit only considered the vegetative unit as a potential sink for TSP pollutants. The ground also acts as a sink for TSP and therefore it can be assumed that additional TSP pollutants will be absorbed by the hypothetical vegetative unit. Therefore, it can be concluded that if all the available land were developed into an open space plan in the areas of analysis, then TSP standards would be maintained.

In order to verify this conclusion, a calculation was made to determine the ambient concentration of TSP within the two areas of analysis. To determine concentration levels, it was first necessary to calculate the emission density (Epo) in each area. After finding Epo, the curve in Figure IV-7 was used to calculate ambient concentrations of TSP. These calculations are presented below:

Epo (Area 1) = (Total Emissions in Area-Emissions Taken Up) Total Area
= (94,967 tons/yr - 37644.5 tons/yr) /751.4 mi^2
= 76.3 $tons/mi^2/yr$
= 58 $\mu g/m^3$ annual geometric mean TSP

Epo (Area 2) = (5364 tons/yr - 1119.7 tons/yr) /46.24 mi^2
= 91.8 $tons/mi^2/yr$
= 60 $\mu g/m^3$ annual geometric mean TSP

The previous calculations demonstrate that if all the available land were developed into an open space plan in the areas of analysis, then the ambient concentration of TSP would be below the standard for TSP. Thus, using an open space plan, it would be possible to maintain the standard for TSP.

Based on this conclusion, an open space plan was developed for the land area in the AQMA that was physically beneath the TSP isopleth of 40 $\mu g/m^3$ and above and that was available for open space development. The final open space plan for these areas is illustrated in Figure IV-8 .

c. Street Tree Plan for TSP

In addition to the open space plan in Figure IY-8, an examination was made of street tree plantings to determine their effectiveness of removing TSP. It is hypothetically proposed to plant trees on both sides of the streets within the city boundaries of St. Louis and then to determine how effective street trees may be in removing particulates from the atmosphere. The trees would be thirty (30) feet, (8.5m) apart. The total length of streets in St. Louis is approximately 2,316.25 linear kilometers or 6,600,000 linear feet. Therefore, 440,000 trees would be needed to complete the project (i.e. 6,600,000 ft./30 ft. x 2 = 440,000 trees).

The three tree species proposed to be used for street plantings include red oak (*Quercus robur*), Norway maple (*Acer platanoides*), and linden (*Tilia Cordata*). Table IV-5 presents the dimensions of the tree species and the calculations for determining the amount of particulates absorbed by the 440,000 street trees. Therefore, if the specifications for planting street trees in St. Louis were followed, approximately 340 tons of particulates/year may be removed from the air by trees with similar dimensions to those that appear in Table IV-5.

d. Open Space Plan for SO_2

Emissions of sulfur oxides are the result of the combustion of fossil fuels which contain sulfur. The majority of the fossil fuel burning is done by utility and industrial bailers for the production at steam which is used

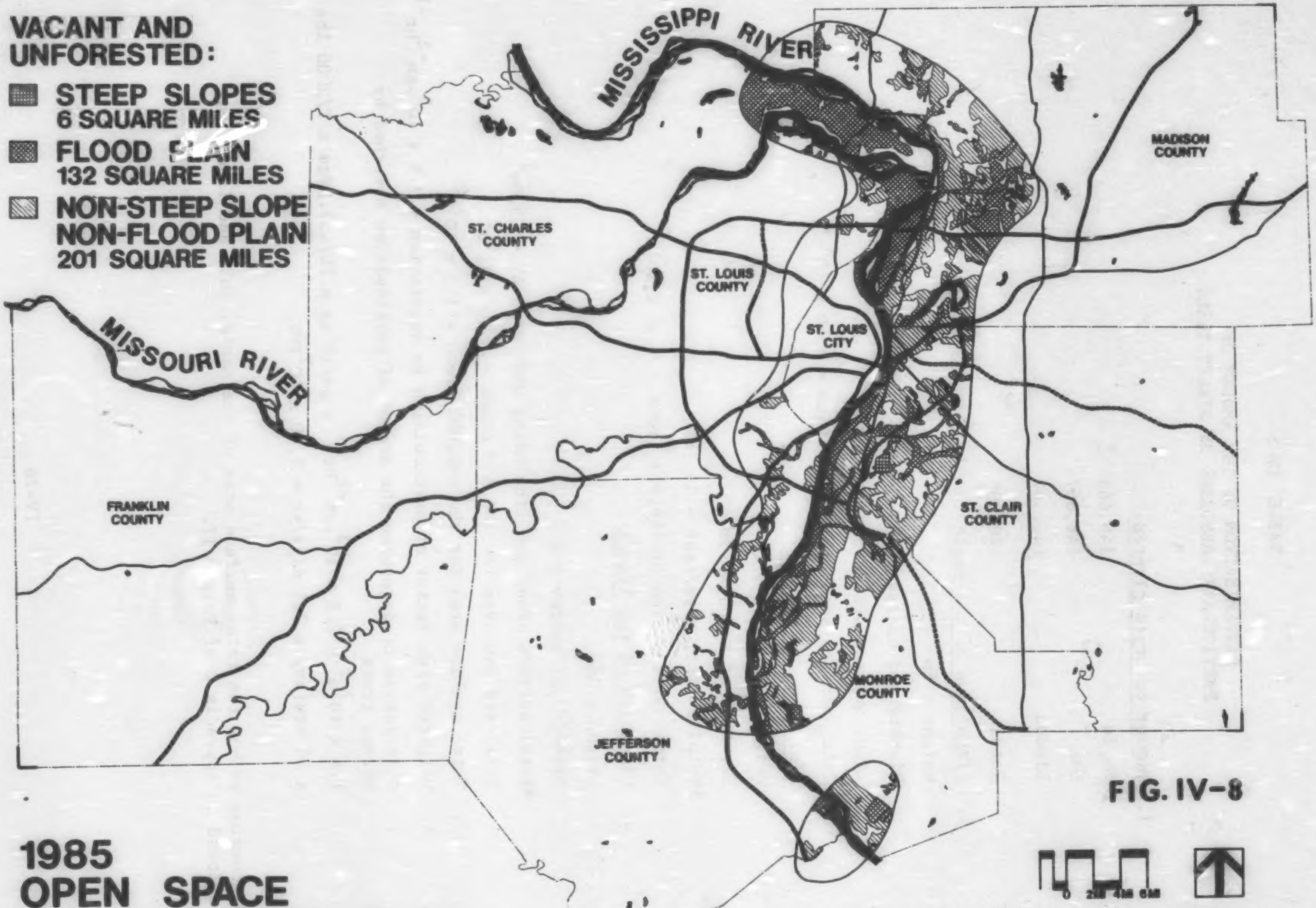

VACANT AND
UNFORESTED:
▦ STEEP SLOPES
6 SQUARE MILES
▩ FLOOD PLAIN
132 SQUARE MILES
▨ NON-STEEP SLOPE
NON-FLOOD PLAIN
201 SQUARE MILES
MISSISSIPPI RIVER
MISSOURI RIVER
ST. CHARLES COUNTY
ST. LOUIS COUNTY
ST. LOUIS CITY
MADISON COUNTY
ST. CLAIR COUNTY
MONROE COUNTY
JEFFERSON COUNTY
FRANKLIN COUNTY
0 2M 4M 6M

FIG. IV-8

1985
OPEN SPACE
IMPROVEMENTS PLAN

ST. LOUIS METROPOLITAN AREA

TABLE IV-5

DETERMINATION OF THE AMOUNT OF PARTICULATES ABSORBED BY STREET TREES

1. Number of trees planted

Maple	146,666
Oak	146,667
Linden	146,667
Total	440,000

2. Dimensions of the maple

Height = 6m

Diameter of canopy = 3m

*Total surface area/tree = 36.8m^2

Total surface area of 146,666 trees = $5.40 \times 10^6 m^2$

3. Dimensions of the oak

Height = 6m

Diameter of canopy = 3m

*Total surface area/tree = 36.1m^2

Total surface area of 146,667 trees = $5.30 \times 10^6 m^2$

4. Dimension of the linden

Height = 5m

Diameter of canopy = 2.4

*Total surface area/tree (including undergrowth) = 23.0m^2

Total surface area for 146,667 trees = $3.40 \times 10^6 m^2$

5. Total surface area for the 440,000 trees = $1.4 \times 10^7 m^2$

6. Weighted sink factor of particulates by vegetation = $2.5 \times 10^3 \mu gm^{-2} hr^{-1}$

7. Calculation to determine the amount of particulates absorbed by street trees

$1.4 \times 10^7 m^2 \times 2.5 \times 10^3 \mu gm^{-2} hr^{-1} \times gm/10^6 \mu g \times lb/453.59gm \times T/2000\ lbs$

$\times$ 24 hrs/day $\times$ 365 days/yr = 3.40×10^2TPY

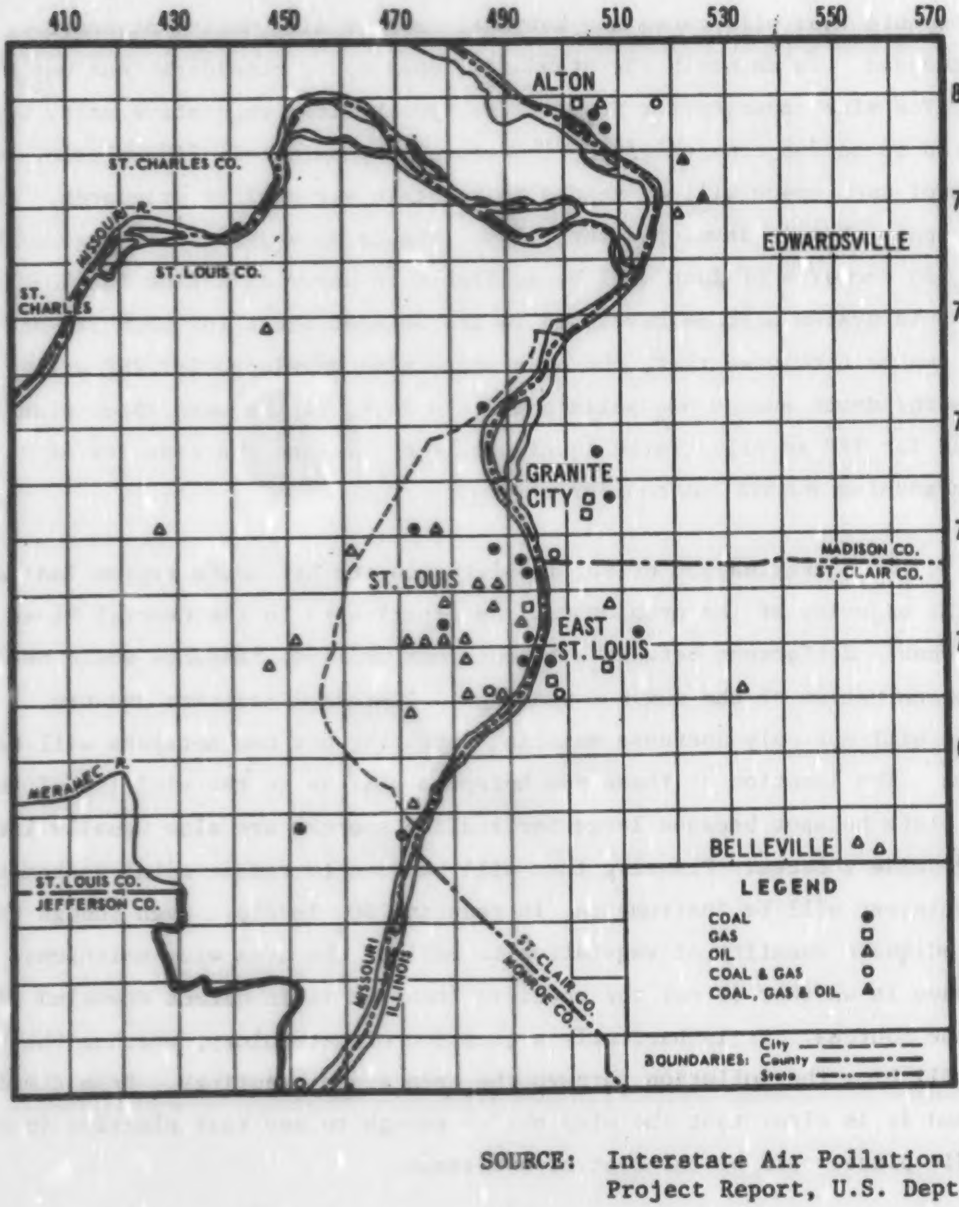
*Discussion on how the total surface area of the maple, oak, and linden may be found in Appendix C of Volume II.

either to produce electricity or to provide process steam. Figure IV-9 illustrates the location of major fossil fuel users in the metropolitan St. Louis area. Because these users are also the major sources for TSP pollutants, the hotspot areas idenitified in Figure IV-6 for TSP, can also be considered the major problem areas for SO_2. According to the previous discussion, there will be 186,053 tons/yr. of sulfur oxides in 1985, being emitted into the atmosphere that will cause the National Ambient Air Quality Standard to be exceeded. To maintain the standard , open space considerations may be useful. The sink capacity for SO_2 for the hypothetical vegetative unit, was calculated to be 748 tons/unit/yr. Therefore, approximately 249 units or 249 hectares of open space will be needed to maintain air quality standards. If an open space plan is developed for TSP pollutants as suggested in Figure IV-8 then107,655 hectares of land will be available to serve as a sink for SO_2. Because this system will be developed in the hotspot areas for both TSP and SO_2, it can be concluded that, the open space plan developed for TSP will also absorb/adsorb enough SO_2 pollutants. In fact, if the open space plan is developed for TSP as illustrated in Figure IV-8 , it has the capacity of absorb/adsorbing 80,525,940 tons/yr of SO_2.

Examination of SO_2 isopleths in the St. Louis region indicates that the majority of the problem will be experienced in the Central River Region. The probable difference between 1965 readings and 1985 readings would be the concentration of the maximum readings. Increased capacity and new sources will not only increase existing hotspots, but new hotspots will be created. The location of these new hotspots will be in the vicinity of the particulate hotspot because large particulate sources are also usually large sulfur oxide sources. Planting that will be used to reduce total suspended particulates will be instrumental in reducing SO_2 levels. Even though there is an adequate quantity of vegetation to collect the area wide emissions, the issue is whether or not the specific location is in direct downwind line from the sources. It is basically a question of meterology, whether the wind will blow the pollution through the open space plantings. From the isopleths examined it is clear that the wind shifts enough to say that planting in one specific place would be the most adventageous.

FIGURE IV-9

LOCATIONS OF FUEL CONSUMERS THAT USE
565 x 10^9 OR MORE BTU PER YEAR


410
430
450
470
490
510
530
550
570
810
790
770
750
730
710
690
670
650
630
ALTON
EDWARDSVILLE
ST. CHARLES CO.
MISSOURI R.
ST. LOUIS CO.
ST. CHARLES
GRANITE CITY
MADISON CO.
ST. CLAIR CO.
ST. LOUIS
EAST ST. LOUIS
MERAMEC R.
BELLEVILLE
ST. LOUIS CO.
JEFFERSON CO.
MISSOURI
ILLINOIS
ST. CLAIR CO.
MONROE CO.
LEGEND
COAL ●
GAS □
OIL △
COAL & GAS ○
COAL, GAS & OIL ▲
BOUNDARIES: City
County
State

SOURCE: Interstate Air Pollution Study, Phase II
Project Report, U.S. Dept. HEW, May/1966

e. Carbon Monoxides

A large portion of the carbon monoxide is contributed by mobile sources, especially the automobile. From the previous discussion, it was concluded that no reduction in carbon monoxide will be required. The National Ambient Air Quality Standard for carbon monoxide will be achieved sometime between 1975 and 1980.

There are two governmental programs that are responsible for the expected reduction. These programs are the Federal Motor Vehicle Pollution Control Program and the St. Louis Transportation Control Plan. The Federal program reduces ambient levels of carbon monoxide, by making sure that new cars emit less pollutants by inducing the manufactures to incorporate control devices and design changes into the new model cars to achieve legislatively determined emission standards. The major elements of the TCP are an Inspection Maintenance Program to ensure proper operation of the control devices, and Mass Transit inducement and improvement to entice the commuters to leave their automobiles for less polluting form of transportation.

If carbon monoxide had been a problem, the specially designed hectare could accomodate 2.2 tons/year of carbon monoxide. Even though a region plan for attainment of the standards is not needed, plantings of open space in the vicinity of intersections may be helpful in reducing localized hotspots.

Carbon monoxide hotspots usually occur in localized areas of idling traffic, primarily at intersections. Buffer strips planted in the vicinity of the hotspots may reduce a substantial amount of the carbon monoxide emissions. In Volume II, there are potential designs for developing buffers and also, for improving the sink capacity of these vegetative groupings. The following are some guidelines for developing effective buffers for removing pollutants. Additional recommendations may be found in Volume II.

First, a thirty-foot setback of the planting areas from the road should be maintained otherwise the vegetation may interfere with the drivers' safety. The vegetation which is planted outside this critical area may be either organized into hedgerows composed of shrubs and small trees or forests.

The most effective arrangement of hedgerows depends on the direction of the prevailing wind, location of the polluting source, variations in topography, and other factors. Correct placement of the hedgerows allows maximum exposure of the plant surfaces to the air pollutants. Figure IV-10 shows the arrangement of hedgerows in a chevron pattern which is a very effective design for removing air pollutants. Another design presented in Volume II is arranging the buffers in such a way that they are parallel to the road and relatively perpendicular to the prevailing winds. The arrangement causes wind disruption which allows a greater opportunity for the vegetation and soil to absorb the carbon monoxide in addition to other airborne pollutants. Figure IV-10 shows this parallel hedgerow arrangement also.

Dense buffers can hinder the dispersion of carbon monoxide. By cutting through the vegetation, ventilation will be enhanced and localized concentrations of carbon monoxide will be minimized. Another advantage for forming corridors through dense buffers is that the vegetative edge will be increased which aids in removing pollutants. Figure IV-11 illustrates the technique of increasing buffer ventilation and the edge effect of a dense buffer. Other recommendations for improving the sink capacity of both hedgerows and forests are in Volume II.

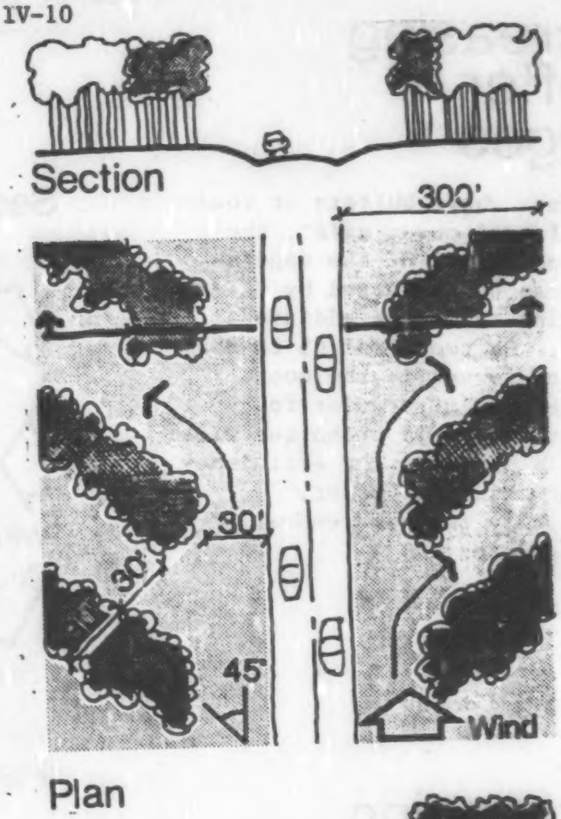
f. Hydrocarbons

From the literature search completed in Volume I of this study, very little evidence of hydrocarbon uptake by vegetation was discovered, on the contrary, the available literature indicates that vegetation acts as a source of hydrocarbon emission.

FIGURE IV-10

Chevron Hedgerow

The alignment of discontinuous hedgerows in a chevron pattern will provide a large area of leaf surface contact for adsorption of particulates and absorption of soluble gases. The gaps between the plantings provide adequate ventiliation for CO dispersion. The belts should be oriented at a 45 degree angle to the road; in the direction of the prevailing winds. A 30' safety setback should be maintained.



Parallel Hedgerow

In situations where existing woodlots or buffers are parallel to the road and relatively perpendicular to the prevailing winds, the placement of a discontinuous hedgerow windward of the edge of vegetation, as shown, will increase wind turbulence and decrease wind speed thereby causing particulates to drop out. The polluted air is forced closer to the soil surface where CO can be metabolised by soil organisms. The increased exposure of leaf surfaces further reduces particulates and allows for the absorption of soluble gases. Openings in the hedgerows are located at intervals to limit the buildup of CO. A 30' safety setback should be maintained.

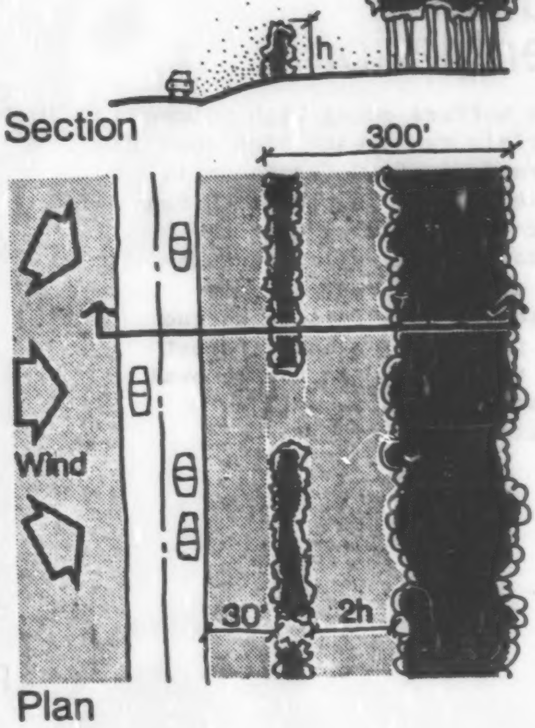
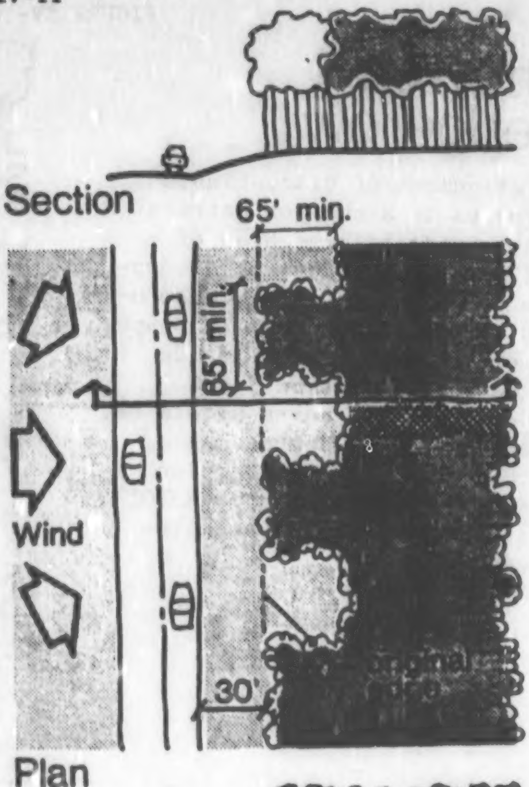


FIGURE IV-11

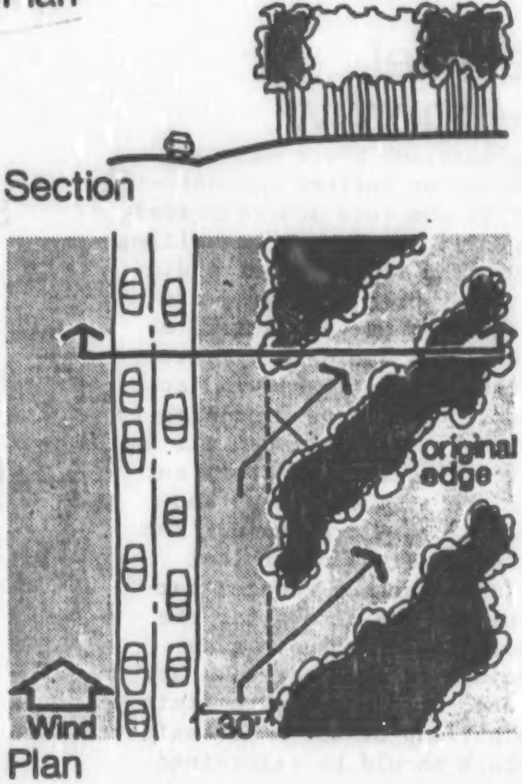
Increasing Buffer Edges

In cases where buffers or roadside forest cover exist, the sink potential of the vegetation can be increased by clearing to create additional edges. As the first 65 to 85 feet of forest is the most valuable as a receptor for pollutants, this technique will greatly increase the efficiency of the existing buffer, especially for the removal of particulates.



Increasing Buffer Ventilation

Dense buffers along high volume arterials can create high concentrations of CO (as shown in Figure II-15. To reduce CO concentration, cuts through the vegetation will allow ventilation of the roadway and dispersion of CO. This technique also provides increased forest edge thus aiding in the removal of particulates as well as soluble gases.



Hydrocarbon emissions from cars in the St. Louis area cannot be reduced through an open space plan. The reductions must be accomplished through administrative control strategies such as transportation control planning, AQMA Planning, and the Federal Motor Vehicle Pollution Control Program.

To determine whether or not vegetation will be beneficial in reducing oxidants, it is important to understand the process by which oxidants are formed. According to the U.S. Department of Health Education and Welfare, there exists an ongoing cycle involving nitrogen dioxide, sunlight energy, oxygen atom, ozone, and nitric oxide. This cycle called the photolytic cycle is illustrated in Figure IV-12. If the cycle is allowed to proceed without interference it will maintain the proper balance of chemicals in the atmosphere. The key element in the cycle is that nitric oxide and ozone cannot co-exist. They will react quickly to produce nitrogen dioxide and oxygen molecules.

As specific pollutants are released into the atmosphere such as hydrocarbons, they will interfere with the cycle such that an overload in oxidants will occur. Reactive hydrocarbons such as 1.3 Butadiene, 2 Alkenes, and 1,3 & 5 Trimethylbenyene interfere with the normal phololytic cycle as shown in Figure IV-13. What happens is that the oxygen atom combines with the hydrocarbon atom to form a hydrocarbon free radical which then reacts with the nitric oxide. This reaction leaves the ozone fewer nitric oxide atoms to react with which causes a build-up in ozone concentration.

In understanding whether or not open space plantings will reduce oxidants it must be determined what effect the planting will have on hydrocarbons, nitrogen dioxide, and ozone. From Volume I : Sink Factors, white oak will absorb 63.5×10^3 μg/m/m^2, white birch will absorb 53.6 g/m/m^2 and alfalfa will absorb 169.20×10^5 μg/m^2/m of nitrogen oxides. In general the plantings generate hydrocarbons. Globally, vegetation generates 100 million tons/year of hydrocarbons. The exact effect of plantings on the oxidant problem is uncertain. To determine whether the net effect is positive or negative, these generation rates should be entered into an analytical model of the photolytic cycle. Doing this is beyond the scope of the current contract, so the issue must be deterred for the present. Much more research has to be done in this area before definite conclusions can be drawn concerning the net effect of vegetation on oxidant concentrations.

FIGURE IV-12

ATMOSPHERIC NITROGEN DIOXIDE PHOTOLYTIC CYCLE

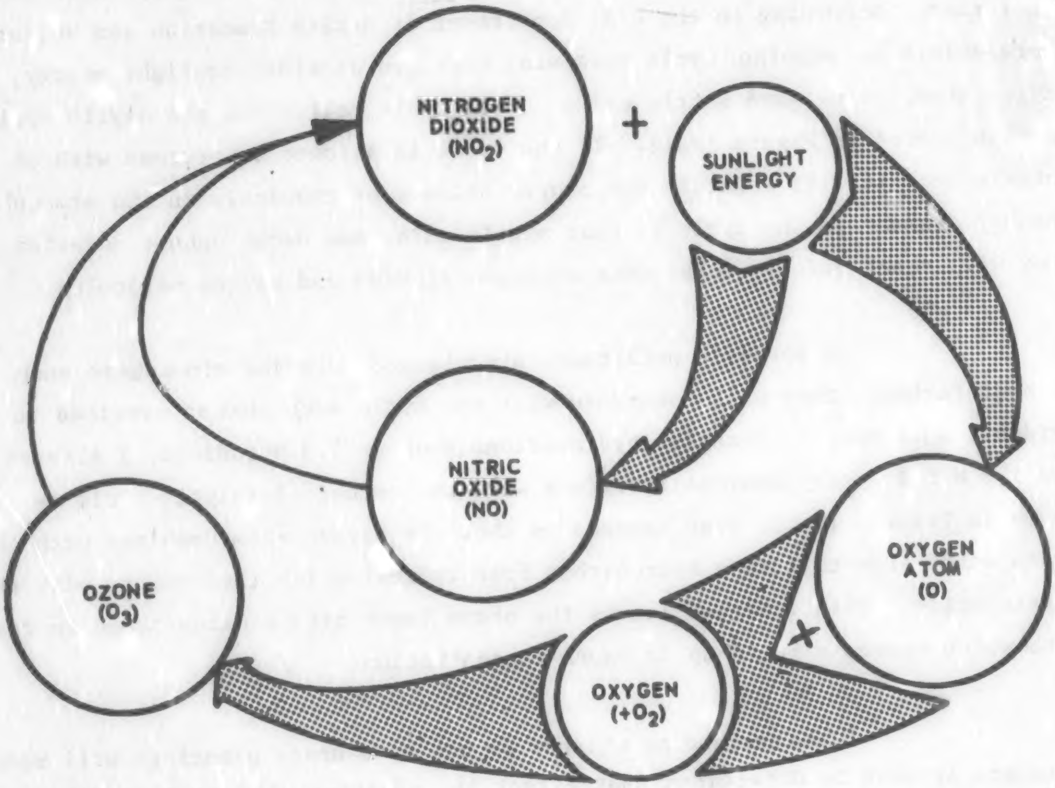
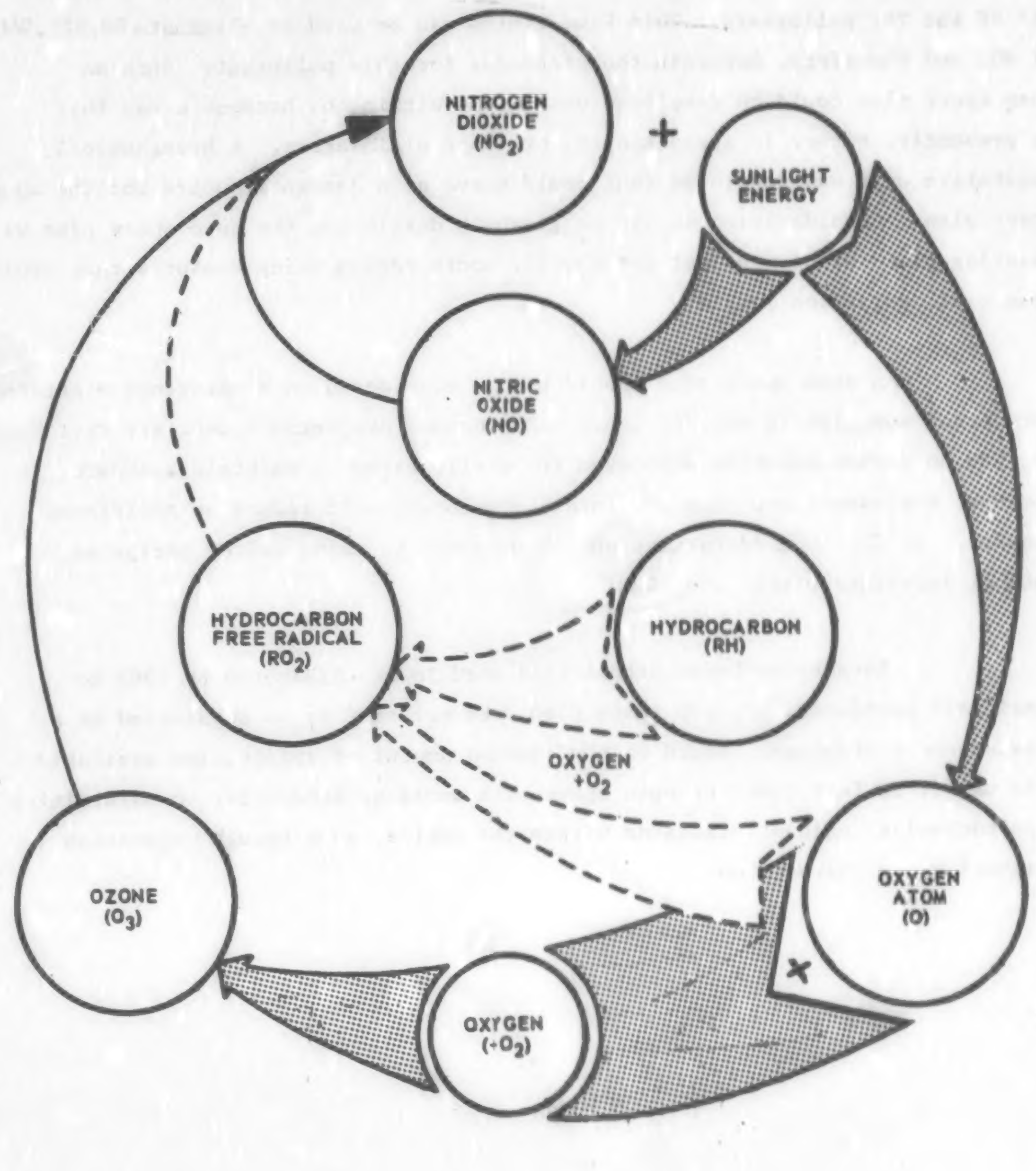

NITROGEN DIOXIDE (NO_2)
+
SUNLIGHT ENERGY
NITRIC OXIDE (NO)
OXYGEN ATOM (O)
+
OZONE (O_3)
OXYGEN $(+O_2)$

FIGURE IV-13

INTERACTION OF HYDROCARBONS WITH ATMOSPHERIC NITROGEN DIOXIDE PHOTOLYTIC CYCLE


NITROGEN DIOXIDE (NO_2)
+
SUNLIGHT ENERGY
NITRIC OXIDE (NO)
HYDROCARBON FREE RADICAL (RO_2)
HYDROCARBON (RH)
OXYGEN $+O_2$
OXYGEN ATOM (O)
OZONE (O_3)
×
OXYGEN ($+O_2$)

4. Conclusions.

In order to maintain air quality standards in the St. Louis AQMA by 1985, 44,106 tons/yr. of TSP and 186,053 tons/yr. of SO_2 need to be eliminated after air standards are obtained. By using the available land in the TSP hotspot area, it is possible to develop an open space plan that will absorb or adsorb all of the TSP pollutants. This same system can be used to eliminate 80,525,940 tons/yr. of SO_2 and therefore, maintain the standards for this pollutant. Such an open space plan could be developed using land within the hotspot areas that is presently, either in steep slopes, or flood plain areas. A hypothetical vegetative unit was developed that could serve as a design standard for the open space plan. Consideration should be given to developing the open space plan within existing plans of development for the St. Louis region using measures that could reduce air pollution levels.

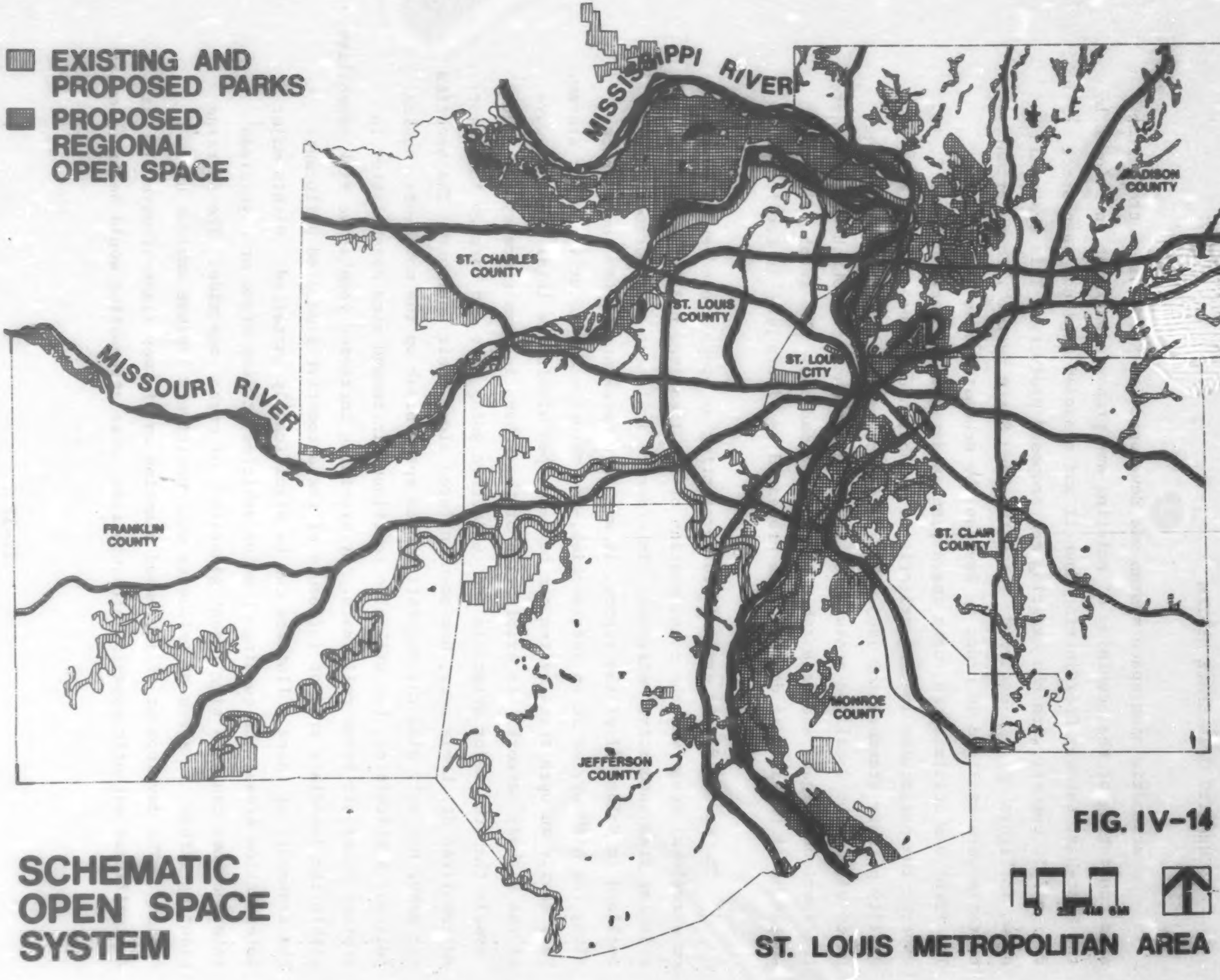
An open space plan should not be considered as a maintenance strategy for carbon monoxide in the St. Louis AQMA because projections indicate that by 1985 no carbon monoxide will need to be eliminated to maintain standard. However, the open space plan previously developed could reduce an additional tons/yr. of CO. Considerations should be given to using buffer strips at hotspot locations within the AQCR.

Because no hydrocarbons will need to be eliminated by 1985 to maintain standards, an open space plan does not need to be considered as a maintenance strategy. Based on the limited amount of information available to us, it is felt that the open space plan would be beneficial to maintaining photochemical oxidant standards within the region, even though vegetation itself emits hydrocarbons.

C. SCHEMATIC OPEN SPACE SYSTEM

A schematic open space system was developed for St. Louis metropolitan area consisting of the combining of existing and proposed parks as envisioned by the East-Wast Gateway Coordinating Council and proposed regional open space designed in concert with the existing and proposed products. This system is shown in Figure IV-14, entitled "Schematic Open Space System". Three primary criteria were utilized in order to develop the schematic open space system. The first was utilizing the open space plan as designed in Section B and C, to control the particular loading criteria as established by the national air quality primary standard for 1985. This utilized mass planting of vegetative units within the localized areas which we are experiencing or which were projected to experience higher and acceptable particular loadings. The graphical representation of the plan as designed was presented as Figure IV-8 in Section 4C.

The second design criteria for presenting an overall open space system on a regional scale was the consideration of the localized pollution sources existing from automotive emissions. In order to implement the recommendations outlined in Volume II of the report, it was felt necessary to use open space along the highway, or at an intersection, and maintain a vegetative buffer system. Very easily an open space system can be developed within the legal right-of-ways of the highway network. An examination of the schematic open space system figure reveals that the major arterials and collectors going into and through the major metropolitan St. Louis area, has been buffered along their entirety. The benefits are many; not only will the vegetative open space break up the movements causing fall-out particulates, but will also contribute increased sink capabilities to capture other air borne pollutants. By providing increased vegetative sink capability within the immediate area of influence of the automotive generated pollutants the transport of these pollutants can be significantly curtailed. Within major intersection areas, the queuing of motor vehicles at stop signs or signalized intersections causes a significant generation of carbon monoxide. The increase planting within the areas of influence will positively improve ambient air quality. The development of increased planting on highway right-of-ways also has a significant esthetic appeal. Although some noise attenuation would be experienced


EXISTING AND PROPOSED PARKS
PROPOSED REGIONAL OPEN SPACE
MISSISSIPPI RIVER
MISSOURI RIVER
MADISON COUNTY
ST. CHARLES COUNTY
ST. LOUIS COUNTY
ST. LOUIS CITY
ST. CLAIR COUNTY
FRANKLIN COUNTY
MONROE COUNTY
JEFFERSON COUNTY
0 2 4 6 MI

SCHEMATIC OPEN SPACE SYSTEM

FIG. IV-14

ST. LOUIS METROPOLITAN AREA

by any planting, the right-of-ways are not deep enough to provide sufficient depth of dense plantings to significantly cause noise reduction from the motor vehicle traffic. The separation of noise generations sources such as the highway from nearby receptors (schools, housing complexes, etc.) can have definite positive psychological effects, however.

The third major criteria for creating the schematic open space system was predicated on the most important design constraint, this being the proposed land use planning policies by the East-West Gateway Coordinating Council for use of their land for conservation and leisure. The Council established far reaching goals, objectives, and policies for their use of recreational and open space land. Their overall goal was to provide for adequate open space and recreation areas in harmony with the natural environment for the use and enjoyment of all citizens of the St. Louis region. The achievement of this major goal will be realized through several provisions of the plan. The two major provisions include providing recreational facilities and preserving and enhancing the natural environment. It is with in this need to preserve and enhance the natural environment, which directly influenced our proposed open space system. The East-West Gateway Coordinating Council had five major objectives which they were attempting to achieve. By planning for conservation and leisure lands in the future. These objectives included:

- The creation of a permanent regional space system which will guide the expanding urbanized area into a pattern of radial corridors
- The providing for esthetically pleasing areas such as; landscaped waterways, parkways, parks, greenbelts and other dedicated open spaces to afford a visual contrast to city buildings and streets.
- The utilization of land considered unsuitable for urban development as recreation or open space areas to include derelict land, land having steep slopes, flood prone land, and those lands which have unstable soils.
- The preservation of significant vegetation and wildlife areas, shorelines, and those areas having unique geological or physiographic formations.

- The coordination of the location and scheduling of recommendations with other functional planning elements

The Council adopted several significant policies with which to implement and to attain the objectives the outlined above. All policies described within their conservation plan supports and provided the controls for our designing the schematic open space system to act as an overall air quality improvement measure.

The East-West Gateway Coordinating Council established park and recreational standards based upon recommendations of the National Recreation and Park Association. These standards vary from totlot type of facilities to regional park facility. The types of parks that fit within the proposed schematic open space plan include the regional park which is designed to serve entire populations in small communities and may be 600 or more acres are usually located within one hour of driving time of the user. The next category is the metropolitan parks which are of 100 - 250 acres and are situated within one half hour driving time of a community of approximately 50,000 people. The last category are the district parks which range in size from 20 to 100 acres and are within one half to three miles of the population being served. The plan as envisioned by the East-West Gateway Coordinating Council identified needs in all of these categories. The projected needs through 1985 included for the study area some 22,000 acres additional for regional parks, 8,000 acres for metropolitan parks, and 4,000 acres for district parks. In order to satisfy the projected needs for regional recreation resources the plan has identified what natural resources can best serve these needs. Those areas which were deemed desirable from a regional park plan concept fit in very well with the open space schematic plan that has been proposed in this report. The major environmental feature criteria included not only those areas with unique recreational potential, but also those areas of natural landscape seems to discourage or cause difficulties for urban development. Such areas include those land subject to flooding or areas of steep slope and those which have less than desirable development soils.

The plan points out the desirability of designating flood prone lands as permanent open space. These lands are defined as experiencing flooding once every one hundred years and have been included in the schematic plan. In order to establish a regional park and conservation system the plan has made significant proposals for conservation areas, forest preserves, agricultural protection areas, and regional parks or recreational areas. The conservation areas have been defined as approximately 103,000 acres of predominantly natural land. The forest preserves which though not needed for the air quality improvement part of the study have been defined as encompassing some 265,000 acres which have significant recreation potential for hunting, camping, hiking, nature study, and wildlife preservation.

The other major areas to be conserved include the agricultural protection area or the lands which experience the possibility of floods. These are usually the agricultural or other low intensity land uses and the development of such lands into a greenbelt system assures a continued protection of the flood prone land.

The schematic open space system presented as Figure IV-14 is composed of several wedge type land areas which encompass the previously described lands having recreational and open space capability. The primary wedge closely follows the Mississippi River and encompasses approximately 339 square miles of land area which should be planted to serve as an efficient receptor of air borne particulates. In addition to improving the air quality of the region the land use proposed would represent an outstanding recreational and environmental management resource. By designating and/or preserving these lands as public open space the many miles of Mississippi River and its tributaries would be preserved. Another very significant open space wedge lines the Missouri and the Merimec flood plain and reaches out to the western half of the region. At the present time, the Meramec River corridor is currently being considered for a proposed regional park and land aquisition is in progress. The schematic open space plan has been designed not only to fit within the proposed park plan, but also to create links between parcels of existing and proposed parks.

A major element of this schematic open space plan is that now open space per se has values in addition to being "nice" land suitable for recreational and esthetic purposes. By supporting the air quality maintenance plan objectives, open space can make a tangible contribution to the "cost" of providing clean air to the region. Open space no longer needs to stand alone without "economic" benefits. Those intangible esthetics and quality of life values are historically assigned to such lands but need to conserve and maintain open land receives additional support from the concept that vegetative units act as air pollution sinks.

V. COST-EFFECTIVENESS ANALYSIS

A. OVERVIEW

Cost-effectiveness analysis is used to make a rational choice among alternative methods to achieve a given objective. It provides a methodology to determine which of a given number of alternative strategies all designed to produce a given level of output is the most efficient or least expensive. For this type of analysis the criterion must be specifiable. Measurement of the costs involved in producing this output is then analogous to estimating the cost component of a benefit-cost analysis.

There are two basic approaches to cost-effectiveness analysis. In a constant-cost study, the objective is to determine the outputs that can be produced under alternative strategies, with these strategies requiring the same cost commitment. In a least-cost study, a fixed objective is stated and then the cost of realizing the objective under alternative strategies is measured.

The objective in this study was to compare the effectiveness of the Open Space Plan in achieving the same reduction of pollution levels in the St. Louis region as the proposed Air Quality Maintenance Area Plan (AQMA Plan). Thus, given the reduction of pollutants expected from implementation of the AQMA Plan as our fixed objective criterion, our methodology was to determine which alternative represents the least-cost method of achieving this objective.

The AQMA Plan was designed to maintain the following primary ambient air quality standards.

Particulate matter - 75 g/m^3 - annual geometric mean
260 g/m^3 - maximum 24 hour concentration (not to be exceeded more than 1 time/yr.)

Sulfur dioxide - 80 g/m^3 - annual arithmetic mean
365 g/m^3 - maximum 24 hour concentration (not to be exceeded more than 1 time/yr.)

Carbon monoxide - 10 g/m^3 - maximum 8 hour concentration (not to be exceeded more than 1 time/yr.)

Photochemical oxidants - 160 g/m^3 - maximum 1 hour concentration (not to be exceeded more than 1 time/yr.)

It was established in the early stages of the study that the Open Space Plan would be more effective in reducing certain individual pollutants and less effective in reducing others. For example, open space can be used to reduce concentrations of sulfur dioxide and particulates, but would cause an increase in levels of hydrocarbons. The AQMA Plan has been developed to produce lowered levels of all four pollutants, but carbon monoxide levels will, in the future, be lowered because of other federal control strategies. These strategies, such as emission regulations in motor vehicles, will produce improved Co levels independent of what the AQMA Plan proposes. It was therefore decided that a comparison of the AQMA Plan and the Open Space Plan, in terms of cost-effectiveness, would be made for the reduction of total suspended particulates and sulfur dioxide to the level set forth in the primary ambient air quality standards.

Once the ambient air quality standards for sulfur dioxide (SO_2) and particulates have been attained in the St. Louis region, an additional 186,000 tons annually of SO_2 and 44,000 tons of particulates will have to be removed from the atmosphere by 1985 to maintain these standards.

Evaluation of study findings described earlier indicated that the amount of open space needed to achieve the needed reductions in particulates were beyond the realm of feasibility. Removal of 44,000 tons of particulates/year would necessitate the creation of dense plantings on more than 100,000 hectares (250,000 acres) of open space. This would represent a significant portion of the undeveloped acreage in the St. Louis region and capital expenditures approaching 4 billion dollars.* The magnitude of this amount is such that no detailed comparison of open space vs. the AQMA Plan was undertaken.

The following cost-effectiveness analysis is thus limited to a comparison of the net costs for each of the two alternatives to remove 186,000 tons of SO_2 from the atmosphere by 1985.

*See Appendix A for cost information

B. OPEN SPACE LAND REQUIREMENTS FOR SO_2 REMOVAL

On the basis of our analysis it was established that a total of some 250 hectares (617.5 acres) of properly planted open space would be sufficient to meet the criterion objective of removing 186,000/year of SO_2 by 1985. Examination of various St. Louis regional land use and conservation maps (see Figures IV-1 & IV-2) indicated that the area contained a sufficient quantity of scattered parcels which are presently undeveloped because of marginal physical, economic and/or market characteristics. These parcels are well suited to open space plantings for air quality maintenance purposes and could be used without significant (or even measureable) impact on regional development patterns or land uses and values.*

The number of trees needed to develop a hectare in which the individual tree canopies will be touching by 1985 if these trees are planted in 1977 was calculated as being 1044 trees (one-third deciduous and two-thirds coniferous). The canopy coverage will become more extensive as the years pass, and the more aggressive trees will compete more successfully for the available light. Trees that are shade intolerant will eventually die and natural thinning of the forest will occur. The debris of the dead and fallen trees should not be removed from the forest since the litter as it deteriorates will provide shelter for wildlife and enrich the soil. Any expenditures for thinning or removing debris would be unnecessary.

C. OPEN SPACE COST ELEMENTS

The direct cost elements associated with the Open Space Plan are described below and summarized in Table V-1. They include:

1. Acquisition Costs.

This element includes the direct costs of land purchase by the municipality or regional agency and the attendant costs of legal and administrative staff to negotiate a purchase agreement or initiate a public taking. Since it is assumed that the required acreage can be assembled from parcels in the metropolitan area but which are presently undeveloped and have limited development potential, an average cost (in 1977 of dollars) $5,000/acre ($12,350./hectare) is used for this element. It is further assumed that two-thirds of the acreage will be acquired in the first year of the Plan (1977) and the remainder in the following year (1978).

---

*A detailed parcel-by-parcel analysis to determine such factors suitability of soils and drainage, ownership, availability or optimum components of parcels was clearly outside the scope of this study.

It is recognized that land resources, especially in this case, where no major changes in topography or structures or excavations are planned, have a continuing re-sale potential. However, the present analysis treats this "salvage value" as a non-quantified benefit rather than as a direct off-set against the acquisition cost.

2. Capital Investment Costs.

This element includes the direct costs of: preparing landscaping and engineering specifications and plans; site clearance and minor modifications; purchase, delivery and installation of the trees and installation supervision. Each of those components are shown in Table V-1.

The cost for planting the trees of the vegetative unit was determined by applying a 7% inflation to the 1976 average wholesale prices. In addition, a 50% increase is added to the cost of the trees which is assumed to cover the landscape contractor's installation costs, overhead and profit. The relatively low overhead multiplier assumes that the efficiency of planting large numbers of trees will be reflected in the cost. Approximately $1,600/hectare is the estimated cost of clearing and grubbing the land.

It is assumed that purchased services and materials will be in sufficiently large quantities to permit economies of scale and that about one-third of the actual plantings would occur in 1977 with the remainder in 1978.

3. Loss of Tax Revenues.

If all of the acreage to be acquired and planted is currently in private ownership, conversion of the land to public ownership would entail a loss of tax revenues to local municipalities. Assuming that an average hectare has a current market of $11,115 (in 1977 dollars)($4,500/acre) and using the prevailing regional tax structure, the dollar cost of this element can be established. The prevailing assessment ratio in the area is 30% of market value and the 1976 average mill rate is approximately $62.70/thousand dollars of assessed value. Adding a 7% inflation factor to this rate to translate it into 1977 dollars, yields an effective tax rate of $20.13/thousand dollars of market value. Application of this figure provides a tax loss averaging $223.74/hectare annually. This cost is incurred at the time at which the land is acquired and title transferred, and every year thereafter.

4. Annual Operating and Maintenance Costs.

The individual planted parcels will be designed for natural growth and self-regulation thus requiring a minimum of maintenance. However, a certain amount of effort and manpower will be required on a regular basis for inspection, public security control, remedial action in the event of severe climatic conditions, plant disease, etc. The annual cost of this effort is assumed to be 5% of the capital cost.

D. AQMA PLAN COST ELEMENTS

An analysis of four (4) possible SO_2 removal processes was undertaken to establish cost estimates for the 1985 criterion level of 186,000 tons/year. The specific processes and estimating procedures are described in Appendix A. The range of costs was developed from 1974 data and has been brought to 1977 dollars by incorporation of a 7% year average inflation rate.

The four processes exhibited a wide range of costs; both in initial capital investment required and in annual operating costs. For purposes of this analysis the median value of the four (4) processes is used for both of these cost elements; these values are $20,875,000 for the capital cost and $9,482,000 in annual operating costs.

TABLE V-I

COST ANALYSIS
OPEN SPACE PLAN FOR SO_2 REMOVAL
(IN 1977 DOLLARS)

1. Acquisition Cost - 250 Hectares @ $12,350 each = $3,087,500		
2. Capital Investment Cost -		
Estimated cost of planting one hectare -		
Deciduous trees 344 - 2"-2½'caliber trees/hectare @ $39.05 + 50%		$20,152
Coniferous trees 700 - 5'-6' caliber trees/hectare @ $15.00 + 50%		15,730
Clearing/hectare		1,600
Total cost/hectare		$ 37,482
250 hectares @ $37,482.	$9,370,000	
Landscape planning & engineering	180,000	
	9,550,500	
3. Loss of Tax Revenue - Market value/hectare	=	$11,115
assessed value @ 30%	=	3,335
mill rate 67.09/thousand	=	224 /hectare
250 hectare @ $224.00 ea.	=	$56,000 /year
4. Annual Operating and Maintenance Cost -		
5% of $9,550,500.00	=	$477,525 /year

E. COMPARISON OF RATE OF EXPENDITURE FOR OPEN SPACE AND AQMA PLANS

Before the two alternatives can be compared in direct and equivalent terms, it is necessary to identify not only the total expenditures and costs incurred, but also the time frame within which these take place. This step is a necessary prelude to the subsequent calculation of the present worth value of each plan. The annual cost elements required to meet the 1985 target criterion is presented in Table V-II. This cost schedule is determined by the feasible installation rate of the open space program and the anticipated growth and filtering capacity of the planted vegetation. For ease of comparison, the AQMA Plan implementation schedule is matched to this growth rate to yield comparable levels of SO_2 reduction in each year via both approaches.

F. PRESENT WORTH COST-EFFECTIVENESS COMPARISON

In any cost-effectiveness study where costs will occur over a number of years into the future, a time horizon, reference date and rate of discount must be selected. The time horizon must be sufficiently long to capture all relevant costs; however, costs occurring far into the future (e.g. 50 years or more) are not likely to be very significant when discounted back to the reference date.

Determination of a time horizon does not appear to be crucial for this study. Direct, or primary costs of the alternative strategies are concentrated in the early years of the time period. Implementation of the Open Space Plan is assumed to have the same length of time (10 years) as the AQMA Plan. Since the interim maintenance strategies of the AQMA Plan are to be implemented over the 1977 - 85 decade, 1977 is a logical choice for the reference date to which all costs for both strategies will be discounted to net present value.

Each of the cost elements, together with the distribution of its incurrence, as shown in Table V-II,thus must be translated into its 1977 present worth equivalent to permit direct comparison of the two plan alternatives. The present worth of a future expenditure is equivalent to the amount of money that would have to be invested in the present year, at a specified rate of interest, to provide sufficient funds for the future disbursement. The interest (discount) rate selected is an indicator of the time value of money and is chosen to reflect.

Choice of a discount rate poses a greater problem. Many alternatives are often mentioned: the government borrowing rate, the rate of return on private investment and the social rate of time preference. There appears to be some agreement that the rate of return on private investment serves best as a basis for a relevant public discount rate. The opportunity cost of any government's expenditure on resources is their use in the private sector for investment and consumption. Allocation of resources to the former use is determined by the rate of return on private investment, to the latter by the social rate of time preference. In equilibrium, assuming a perfect capital market, these two rates would converge. However, influences such as externalities in investment, taxes, and other constraints on investment tend to keep the rate of return on private investment above the social rate of time preference.

TABLE V-2

RATES OF EXPENDITURE
(IN MILLIONS OF 1977 DOLLARS)

Year	% of Criterion Attained	OPEN SPACE PLAN					AQMA PLAN		
		Acquisit.	Capital	Lost Annual Taxes	Annual Mainten.	TOTAL	Capital	Annual Operating	TOTAL
1977	10%	2.0875	3.5505	.0400	.1500	5.8280	2.0875	.9482	3.0357
1978	30%	1.0000	6.0000	.0560	.4000	7.4560	4.1750	2.8446	7.0196
1979	40%	-	-	.0560	.4775	.5335	2.0875	3.7928	5.8803
1980	50%	-	-	.0560	.4775	.5335	2.0875	4.7410	6.8285
1981	60%	-	-	.0560	.4774	.5335	2.0875	5.6892	7.7767
1982	70%	-	-	.0560	.4774	.5335	2.0875	6.6374	8.7249
1983	80%	-	-	.0560	.4774	.5335	2.0875	7.5856	9.6731
1984	90%	-	-	.0560	.4774	.5335	2.0875	8.5338	10.6213
1985	100%	-	-	.0560	.4774	.5335	2.0875	9.4820	11.5695
	TOTAL	3.0875	9.5505						

Although far more information is available for estimating rates of return on private investment than social time preference rates, existing data on the former need several adjustments before they can be used to approximate a discount rate on public investment. This process must include an adjustment for taxes, which are a deduction from private, but not public returns from investment. The private rate of return on investment must be further adjusted for differential risk. Because government risks are spread over a greater diversity of projects than risks of firms, the typical marginal risk associated with a public project tends to be less than for a privately funded project. Thus the private rate may require an upward adjustment for risk, the extent of the adjustment depending on the nature of the public project.

Third, if a cost-effectiveness analysis is carried out in constant prices, an estimate of the anticipated inflation rate must be subtracted from the private rate of return on investment. The private rate of return is of course a money rate, and the inflation premium must be subtracted to arrive at the real rate.

The existence of capital rationing in the public sector, particularly the local public sector, should not cause any additional adjustments in arriving at the discount rate. Because the basis for the discount rate is a private rate, rationing in the public sector will affect private rates only indirectly by diverting funds to the private sector, driving private rates down. Existing rationing in the public sector will already be reflected in the private rate of return on investment. Only changes in the extent of capital rationing would require an adjustment.

The rate of return on private investment can be determined on the basis of a wide variety of rates; on loans, stocks, bonds, and earnings-price ratios, etc. The most readily obtainable, easiest to adjust, and in our opinion the most justifiable, is 6%-the average of rates paid on new long-term bond issues.

The Open Space Plan consists of various forms of public investment. However, the AQMA Plan includes private as well as public investment, raising the question of the appropriate discount rate to use in this case. However, since the private sector costs for SO_2 reduction are to be incurred primarily by public utilities, which operate in controlled fiscal climates and portions of the investment are most likely to be offset by tax credits, the public sector rate seems appropriate.

No estimate of a single rate is perfect, so often a range of rates is used. Such a 'sensitivity analysis' is probably more appropriate to benefit-cost studies, where benefits may be uncertain and often occur in years after costs have been incurred. In the two pollution reduction plans under comparison, the majority of all direct costs occur over the same ten-year period and the differences in cost effectiveness are substantial. Thus the choice criterion is not likely to be sensitive to modest variations in the discount rate. However, if the comparison were less obvious, a sensitivity analysis would have to be undertaken.

The cost-effectiveness comparison of the two alternate SO_2 maintenance plans is presented in Table V-3 in terms of the present worth of quantifiable direct costs attributable to each. (Intangible costs and offsetting benefits are discussed below). The most significant point of comparison is in terms of the 1977 present worth of achieving the 1985 criterion of removal of 186,000 tons of SO_2/year. On this basis, the Open Space Plan can attain the objective at less than one-third the cost of the AQMA Plan with equivalent effectiveness.

The advantages of the Open Space Plan are even more apparent if the time frame is extended to 1995 because, once the criterion level is achieved, the Open Space Plan has a far lower annual cost. The difference would be still more pronounced if even longer time periods of life cycles were considered because the Open Space Plan is essentially self-perpetuating; the AQMA Plan on the other hand would require periodic replacement of captial equipment upon wearout.

G. INTANGIBLE COSTS AND BENEFITS

Since both alternatives will serve to eliminate equal amounts of SO_2, the comparison of direct costs can be supplemented by consideration of differing identifiable, but non-quantifiable comparative advantages and disadvantages of each option.

TABLE V-3

SO_2 - SUMMARY COMPARISON OF COST EFFECTIVENESS: OPEN SPACE PLAN vs. AQMA PLAN

CRITERION OF EFFECTIVENESS: Removal of 186,000 tons of SO_2/yr. from the region's atmosphere by 1985.

DIRECT COSTS (IN MILLIONS OF 1977 DOLLARS)

	OPEN SPACE PLAN	AQMA PLAN
Acquistion	$ 3.0875	$ -
Capital Investment	9.5505	20.875
Loss of Annual Tax Revenue (to 1985)	0.0560	-
Annual Maintenance (to 1985)	0.4775	9.482
1977 Present Worth of Above (discount rate at 6%/yr.)	15.6716	54.4471
1977 Present Worth of 1986-1995 direct costs	2.4305	43.1954

COST EFFECTIVENESS:

	OPEN SPACE PLAN	AQMA PLAN
1977 Present Worth Cost/ton SO_2 removed in 1985	84.26	292.73
1985 Effectiveness Advantage Open Space/AQMA Plan	3.47:1	
Effectiveness Advantage to 1995	5.39:1	

AQMA Plan - Advantages

- The AQMA Plan is more labor intensive and requires higher skill levels-this is helpful from an employment opportunity standpoint.

- The AQMA Plan eliminates SO_2 concentrations at their source rather than after it has dissipated into the environment.

- It permits a greater degree of control as to the location, intensity and time frame of SO_2 reduction. The AQMA Plan is more amenable to "crash-programs" in the event of major problems.

AQMA Plan - Disadvantages

- The need for long term equipment replacement and repetitive capital investment.

- Potential for maintenance problems and downtime which can reduce effectiveness or interfere with plant operations.

- The risks of technological development or revised standards which may make equipment outmoded, waste fiscal resource committments, or require additional investment.

- Failure to generate improvements on pollutants other than SO_2.

Open Space Plan - Advantages

- Low risk of obsolescence due to changing technology or standards.

- Cheaper expansion of pollutant filtering capacity.

- Oxygen production

- Creation of green spaces which replace parcels often in litered conditions; thereby generating esthetic and secondary health benefits (elimination of rodents, mosquitoes, etc.)

Open Space Plan - Advantages (Continued)

- Increases in the value, marketability and/or rehabilitation potential of properties adjacent to the open space parcels.
- Generation of potential value capture if land is resold or developed at some future data.
- Low annual maintenance costs and elimination of need for re-capitalization.
- Foliage buffer absorbs noise and reduces ambient levels.
- Improved and more controlled storm water retention.
- High potential availability of Federal, State and Regional matching funds.
- Minimal post-construction monitoring, administrative and control costs and requirements.
- Minimal (less than 1%) concomittant reduction in suspended particulate concentrations.

Open Space Plan - Disadvantages

- Acquisition problems - legal barriers, proceedings, possible need public takings.
- Potential for local, regional or state jurisdictional problems.
- Possible inadequacies in supplies of trees.
- Risks of disease, storms, climatic extremes which can damage tree canopy.

- Variations in effectiveness across seasons.

- Minor construction impacts - noise, dust, traffic.

- Potential increases in vehicle miles of travel, user costs, trip durations and utility costs of open space parcels contribute to increased decentralization. In the present case, the relatively small number of acres required, the scattering within the region and the use of marginal undeveloped parcels all serve to minimize these potential disadvantages.

- Potential for problems in matching open space parcels with local "hot spots" or most efficient locations.

- Time delays to reach full filtering and SO_2 extraction capacity. The only manner in which effectiveness can be accelerated is via planting of excess acreage in the short term with subsequent creation of over-capacity or refurbishing of parcels for other uses.

H. CONCLUSION

After performing the cost effective analysis, two conclusions can be drawn. First, open space is not a cost effective strategy for combating total suspended particulates (TSP), but is cost effective for the control of sulfur oxides. Open space is not cost effective for control of TSP because the amount of land required for plantings is greater than 100,000 hectares and would cost approximately $4,000,000,000 (four billion) for the land and plantings. Similar reductions in air pollution could be achieved through electrostatic precipitators for a fraction of the cost.*

As the cost data is reviewed, it is clear that open space is a cost effective method for controling SO_2 in the ambient air. The size of the open space required to control 186,000 tons/yr. of SO_2 is 250 hectares and each hectare would be planted with 344 deciduous and 700 coniferous trees. To clear and plant 250 hectares would require an investment of $9,550,500 with an annual operating and maintenance cost of $477,525/yr.

---

* See Appendix A for cost information

The cost to control an equivalent amount of SO_2 through mechanical means would be $20,875,000 for capital investment and $9,482,000 in annual operating costs. In comparing the two strategies it is clear that just the operating expenses of the mechanical devices are enough to justify the Open Space Plan.

VI. RECOMMENDATIONS

A. AREAS REQUIRING ADDITIONAL WORK

Based on the perspective which we have gained during the completion of this three volume project, we can identify five areas which clearly should be considered for further research and development. The further evaluation of open space as an air resource management measure would benefit should any of these areas be explored but it would obviously be best were a corrdinated effort made to investigate all the five areas simultaneously. There are apparently only slight differences in the priorities which these areas should be given. Although they are defined here in a decreasing order of importance, the relative importance of the first may be thought of as 10 on a scale of 10 while the fifth may be thought of as 8. The first area concerns the need for a more inclusive and detailed scrutinizing of the relevant foreign literature. Particular attention should be paid the relevant work areas in the literature of Germany, Japan, the Soviet Union, Poland, and Scandinavia. Perhaps the most efficient and interesting way of achieving this coordination would be to provide a means of establishing a newsletter which would be sent to as many of the authors cited in this project as possible. They would be invited to simply provide titles and abstracts of their pertinent work subsequent to 1975, for example. Response to such a request, and the further dissemination of such a newsletter through the initial respondants to their collegues would provide an excellent means of keeping an open space library updated and active. The field is obviously too interdisciplinary to be effectively served by any one professional journal and a simple "newsletter" could be of great value in encouraging good communications within this multifaceted profession.

The second area of concern relates to the sparce hard data one finds relative to emission rates of pollutants from natural components of the environment such as vegetation and soil. Since virtually every natural community consists of several different elements, the more information we can gain about each element, the more accurate will be our associated understanding and prediction.

The third area of concern, and along somewhat the same line of logic, was that we uncovered precious few useful references pertaining to water bodies as sinks and sources for pollutants. However, it is very clear that for such parameters as sulfur dioxide and methane, water bodies may be of great significance. Furthermore, it seems that our potential ability to model aquatic systems may be greater than our ability to model the corresponding aspects of the atmospheric system.

A fourth area which appears weak in the literature concerns the emperical testing of sink and emission factors as they appear in a real-world setting. Experimental laboratory results dominate the procedures used ...there are very useful and more such field oriented research badly needed.

The encouragement of applied research is also needed in the fifth and final area which we feel should receive support. With respect to woody vegetation especially, it is important to know the total leaf surface area in order to calculate total emission or absorptive capacities. However, work providing leaf indexes for different species and different ecological conditions is extremely limited. This is clearly very fundamental research and the accuracy of any calculations related to the physiological activity of vegetation can be no more correct than the information know about the active surface area of the subject vegetation. This must include knowing the surface area involved for different species at different ages in different seasons.

BIBLIOGRAPHY

Comsis Corporation. 1976. "Open space as an air resource management measure - vol. I: sink factors" Contract No. 68-02-2350, 200pp.

Comsis Corporation. 1976. "Open space as an air resource management measure - vol. II: design criteria" Contract No. 68-02-2350, 400pp.

Bellegia, F.L., Mathews, J.C., Poddock, R.E., and Wisler, M.M. 1975. "Update and improvement of the control cost segment of implementation planning program"

East-West Gateway Coordinating Council. 1974. "Sand for conservation and leisure: the 1995 park and recreation areas plan for the St. Louis region" 90pp.

Environmental Protection Agency, RTI Project 41U-762-13, Contract No. 68-02-0607, Task No. 13, 141pp.

Monteith, J.L.,editor. 1976. Vegetation and the atmosphere - case studies volume II. Academic Press, New York, 440pp.

Perry, John H. 1963. "Perry's chemical engineers' handbook." 4th Ed. McGraw-Hill Book Co., New York, 800pp.

State of Missouri. "Missouri state implementation plan - St. Louis portion" Dept. of Environmental Protection, St. Louis, Mo. (Date unknown).

Voorhees, Alan M. 1974. "Development of a trial air quality maintenance plan for the St. Louis AQMSA" Contract No. 68-02-1388, Task Order 5, approx. 150pp.

APPENDIX A

COST INFORMATION FOR COST EFFECTIVE ANALYSIS

A. OPEN SPACE COST INFORMATION

The cost for planting the trees of the cost effective unit was determined by using the 1976 average wholesale prices. In addition, a 50% increase is added to the cost of the trees which is assumed to cover the landscape contractor's overhead and provide a profit. The relatively low overhead multiplier assumes that the efficiency of planting large numbers of trees will be reflected into cost. Approximately $1,500/hectare is the estimated cost of clearing and grubbing the land.

1. Estimated cost of planting one hectare

Deciduous trees	
344 - 2" - 2½ caliber trees/hectare @ $36.50 + 50%	$18,834
Coniferous trees	
700 - 5' - 6' caliber trees/hectare @ $14.00 + 50%	$14,700
Clearing/hectare	$ 1,500
Total cost/hectare	$35,034

2. Estimated cost of planting the hectares used in the Open Space Plan for TSP:

   (107655 hectares) ($35,034 cost/hectare)

   Total cost = $3,771,585,200

The number of trees needed to develop a hectare in which the individual tree canopies will be touching by 1985 was calculated as being 1044 trees. The canopy coverage will become more extensive as the years pass and the more aggressive trees will compete more successfully for the available light. The trees that are shade intolerantwill eventually die and natural thinning of the forest will occur. The debris of the dead and fallen trees should not be removed from the forest since the litter as it deteriorates will provide shelter for wildlife and enrich the soil. Any expenditures for thinning or removing debris would be unnecessary. The forest may be considered maintenance-free.

The landscape architect's fee was estimated for an area in which the municipality has developed adequate base-line data such as topographic and soils maps. In addition, it is assumed that a federal agency, for instance the Forest Service, will provide site supervision. This supervision may be the responsibility of a federal construction manager. With these two considerations, a contract may be submitted by a landscape architect in which the 107,655 hectares are analysed and a plant mix may then be developed as well as planting specifications. This particular contract is estimated to be $125,000 and will require 2½ man-years. The cost of the design-engineering plan is insignificant when the total cost for implementing the Open Space Plan is considered (3.7 billion dollars).

B. AIR QUALITY MAINTENANCE PLAN COST INFORMATION

1. Summary of Cost To Remove 186,000 TPY of SO_2 and 44,000 of Particulates.

To account for the 186,000 TPY of SO_2 to be removed from the air in 1985 to maintain the air quality standard as an interim measure, 4 SO_2 removal processes were applied to the Labadie Power Plant. Each of the four processes were rated at a higher rate of removal than was necessary. The necessary rate of removal was 51.3%. The four processes are the limestone scrubbing (SO_2 recovery rate 85%), the double alkali process (SO_2 recovery 90%), the Wellman-Lord process (SO_2 recovery 90%), and the citrate process (SO_2 recovery 95%). The following chart summarizing the total of capital cost and the annual operating cost.

TABLE VIII-1
SO_2 REMOVAL AT RATED PERFORMANCE (85+% recovery)
FROM LABODIE PLANT
COSTS IN MILLIONS (M) OF DOLLARS

	Limestone scrubbing	Double alkali process	Wellman-Lord process	Citrate process
CAPITOL COST	$68.56	$26.03	$33.498	$25.06
ANNUAL OPERATING COST	$13.12	$17.402	$13.296	$10.56

These figures must be pro-rated to reflect the lower efficiency need to collect the 186,000 TPY of SO_2.

One possible way is to do a linear interpolation using the efficiency of the process and the desired recovery rate of 51.3%. For example, the limestone scrubbing has an efficiency of 85%, to obtain cost data for a 51.3% recovery rate, the capital cost could be multiplied by 51.3%/85%. This process could also be used for the annual operating cost. By using this technique the following costs are determined:

TABLE VIII-2

SO_2 REMOVAL AT RATED PERFORMANCE (51.3+% recovery) FROM LABODIE PLANT COSTS IN MILLIONS (M) OF DOLLARS

	Limestone scrubbing	Double alkali process	Wellman-Lord process	Citrate process
CAPITOL COST	\$41.37	\$14.99	\$19.09	\$13.53
ANNUAL OPERATING	\$7.9	\$9.92	\$7.58	\$5.70

To recover 44.000 TPY of particulates, the emission load was recovered from a fictitious coal burning power plant. The reductions were accomplished through the installation of electrostatic precipitators.

The capitol and annual operating costs for these units are:

Capitol cost	\$2.519
Annual operating cost	\$310,733

All costs are in mid 1974 dollars.

2. Overall Reductions.

Once the TSP and SO_x ambient air quality standards have been achieved, there will be an additional 44,000 tons/yr. of TSP and 186,000 tons/yr. of SO_2 to be removed to maintain the standards throughout 1985. To achieve these reductions the AQMA Plan proposed interim maintenance measures. These measures would be implemented after the standards were attained through the implementation of the attainment strategies. The attainment strategies consist of enforcing SIP regulations. For TSP and SO_2, the interim measures consist of burning municipal refuse in power plants as fuel and instituting SO_2 emission reductions at three major power plants.

By burning trash at the power plant the north incinerator would be shut down, and the south incinerator's load would be reduced. The reduction in emissions would be 1.78 tons/day from both incinerators. There are no indications as to how this project is being carried out, therefore, there is no way to compute the cost differential between the two projects.

The three power plants involved in reductions are the Labodie, Meramec and Sioux Power Plants of Union Electric. According to the Missouri Implementation Plan, the Labodie Plant has four (4) units whose sizes are 5387 mmBTU/hr input. The present emissions from each unit are 90,630 tons/yr of SO_2 and 1106 tons/yr. of TSP. Anticipated removal for 1980 will be 90% SO_2 and 99.5% for TSP. The Portage des Sioux Plant has two (2) units each rated at 4371 mmBTU/hr input. The emissions from each unit are 79,000 tons/yr. of SO_2 and 380 tons/yr. of particulates. The anticipated control for 1980 is 90% removal of SO_2, and 99.5% removal of TSP. The Meramec Plant is not covered in the inventory section of the SIP.

If the SIP anticipated reductions were accomplished, the total reductions of SO_2 would be 468,468 tons/yr. and the total reductions of TSP would be 5158 tons/yr. of TSP. By comparing these reductions to those required to maintain the standards, it is clear that SO_2 reductions far exceed necessary measures, however TSP reductions are not quite sufficient. In contrast, if a 56% reduction were applied to the Lobadie Plant and a 53% reduction were applied to the Sioux Plant to achieve Missouri's emission limitation standards rather than an arbitrary 90% reduction, the total SO_2 reduction is 286,751 tons/yr. - 203,011 tons/yr. from the Labodie Plant and 83,740 tons/yr. from the Sioux Plant. The combined reduction still exceeds the necessary reduction of 186,000 tons/yr.

To simplify the costing analysis it will be hypothesized that 186,000 tons/yr. will be removed from the Labodie Plant. This means 46,500 tons/yr. per unit or a 51.3% reduction.

In February 1975, Bellegia, Mathews, Poddock and Wisler reported on methods to estimate the capital as well as the operating costs for various methods of controlling particulates and sulfur oxides. It was noted that total installed costs for a given process may run 3-4 times the total equipment costs for the usual materials of consturction. Furthermore, it was determined that operating costs for particulate control devices are determined from:

1. the amount of power necessary to maintain the effluent gas flow through the control device,
2. the amount of power necessary to drive the pumps and auxiliary equipment associated with the control device,
3. the cost of water, chemicals, and additional fuel required by the system,
4. the labor required to operate the system,
5. the necessary maintenance and supplies to keep the equipment functioning at the design or operating level,
6. the cost or credit resulting from the disposal of the collected pollutants,
7. the cost of taxes and insurance and the appropriate unit costs for each of these elements.

In developing equations for annual operating costs for SO_2 removal processes simplifications have been adopted and these are listed below:

1. Utilities and raw materials have been determined on the basis of fixed relationships to the process input parameters for each SO_2 control process which are constant over the entire range of application.
2. Operating hourly labor has been specified and fixed for each process with coverage for the full year (365 days) irrespective of the actual days of operation. An additional 20% has been included for supervision and benefits. No allowance for plant overhead has been provided since these plants do not contribute normally to plant output. The hourly rate is a user input variable.
3. Maintenance charges have been taken as a specified percentage of the process capital investment.
4. Taxes and insurance have been taken at 2 ½% of the total capital investment.
5. Conditions for marketing the output from those SO_2 control processes which produce sulfuric acid, elemental sulfur or SO_2 are uncertain.

The processes that are applicable to utilites are the Wellman-Lord Process (SO_2 recovery 90%), the Limestone Scrubbing (SO_2 recovery 85%), the Double Alkali (SO_2 recovery 90%), and the Citrate Process (SO_2 recovery 95%). All these processes are more efficient than the 51.3% efficiency required. To accomplish the comparison the cost equations for these four (4) processes will be evaluated and pro-rated for a 51.3% efficiency.

3. Limestone Scrubbing. (SO_2 recovery 85% - includes particulate scrubbing)

Maximum sized system - 350,000 ACFM

Capital Cost (C.I.) = $1170(\text{ACFM})^{.65} + 125{,}000(\text{E})^{.75}$

(ACFM) = effluent gas flow rate = 596,855 ACFM

(E) = SO_2 emission rate tons/day = 993.2 tons/day

Since the maximum size unit is 350,000 ACFM, 2 units will be necessary 298,427 ACFM each. The emission rate for each will be 496.6 tons/day. The capital cost equation then becomes:

$$\text{CI} = 1170\ (298{,}427)^{.65} + 125{,}000\ (496.6)^{.75}$$

$$= \$4.25 \text{ million} + \$12.89 \text{ million}$$

$$= \$17.14 \text{ million each of 2 units}$$

$$\text{Total CI} = \$34.28 \text{ million}$$

$$\text{annual operating cost (AOC)} = \frac{(\text{ACFM})}{1000}\ (\text{Days}) \left[300(\$/\text{KWH}) + 1.5\ (\$/\text{mmBTU})\right]$$

$$+ (\text{E})(\text{Days}) \left[153(\$/\text{KWH}) + 1.9\ (\$/\text{mmBTU}) + 2.34\ (\$/\text{ton CaCO}_3)\right]$$

$$+ 21{,}024\ (\$/\text{hr.}) + .06\ (\text{C.I.}) + .025\ (\text{C.I.})$$

$(\$/\text{KWH}) = \$0.0150/\text{KWH}$*

$(\$/\text{mmBTU}) = \$1.25/\text{mmBTU}$

$(\$/\text{ton CaCO}_3) = \$8/\text{ton}$

assume: $(\$/\text{hr}) = \$8./\text{hr.}$

Days = 365

therefore :

$$\text{annual operating cost} = \frac{(298{,}427)}{1000}\ (365) \left[300(.0150) + 1.5\ (1.25)\right]$$

$$+ (496.6)(365) \left[153(.0150) + 1.9\ (1.25) + 2.34\ (8)\right]$$

$$+ 21{,}024\ (8) + .06\ (17.14 \times 10^6) + .025\ (17.14 \times 10^6)$$

$$= 6.56 \text{ million/unit}$$

---

*From Appendix II, Bellegia, et al., 1975.

OPERATING DATA INPUT

Power:	Scrubbing 0.30 KWH/ACFM-day
	Alkali handling 360 KWH/ton sulfur
Water:	4.5m gal/ton sulfur
Reheat:	0.0015mmBTU/ACFM-day (utility applications only)
Limestone:	5.5 tons/ton sulfur
Labor:	Fixed at 2 men/shift (with 20% allowance for fringes and benefits)
Maintenance:	0.06 C.I.
Capital Charges:	15-year life
	Taxes, insurance, etc. 2.5% C.I.

USER INPUTS

(ACFM) = Effluent gas flow rate

(E) = SO_2 emission rate-tons/day

(Days) = Annual days of operation

*($/KWH) = Electric power

*($/mm gal) = Raw water

*($/ton) = Limestone

*($/mmBTU) = Reheat (for utility applications)

($/hr) = Labor rate

(i) = Interest rate

---

4. Double Alkali Process. (SO_2 recovery 90%)

The maximum size unit for this process is also 350,000 ACFM. Subsequently, two (2) units each having the following characteristics will be needed to handle the exhaust gasses: (ACFM) = 298,427 and (E) = 496.6 tons/day.

Capital Cost (CI) = $1000\ (298.427)^{.6} + 200{,}000\ (496.6)^{.65}$
= \$1.93 million + \$11.22 million = \$13.15 million/unit
Total CI = \$26.30 million

$$\text{annual operating cost (AOC)} = \underline{(\text{ACFM})}\ (\text{Days}) \left[240(\$/\text{KWH}) + 1.5\ (\$/\text{mmBTU})\right]$$
$$+ (\text{E})\ (\text{Days}) \left[190\ (\$/\text{KWH}) + 1.9\ (\$/\text{mgal } H_2O) + 1.14(\$/\text{ton CaD}) + .19\ (\$/\text{ton NACO}_3)\right] + 21{,}024\ (\$/\text{hr}) + .06\ (\text{C.I.}) + 3.33 + (\$/\text{ton sludge})$$
$$+ .025\ (\text{C.I.})$$

(\$/KWH) = \$.0150/KWH*
(\$/mmBTU) = \$1.25/mmBTU
(\$/m gal H_2O) = \$.10/mgal
(\$/ton CaO) = \$22/ton
(\$/ton/$NaCO_3$) = %50/ton

assume: (\$/hr) = \$8/hr
(\$/sludge ton) = \$2.5/ton

$$\text{annual operating cost} = \frac{(298.427)}{1000}\ (365) \left[240(0.0150) + (1.25)\right]$$
$$+ (496.6)\ (365) \left[190\ (0.015) + 1.9\ (.10) + 1.14\ (22) + .19\ (50)\right]$$
$$+21{,}024\ (8) + .06\ (13.15 \times 10^6) + 3.33 \times (2.5) + .025\ (13.15 \times 10^6)$$
$$= \$8{,}701{,}211/\text{unit}$$

OPERATING DATA INPUT

Power:	Scrubbing 0.24 KWH /ACFM-day
Reheat:	0.0015mmBTU /ACFM-day (utility applications only)
Water:	4 M gal/ton sulfur
Lime (CaO):	2.4 tons/ton sulfur
Soda ash (Na_2CO_3):	0.4 tons/ton sulfur
Labor:	Fixed at 2 men/shift (with 20% allowance for fringes and benefits)
Maintenance:	0.06 C.I.
Capital Charges:	15 year life Taxes, insurance, etc. 2.5% C.I.

* From Appendix II, Bellagia, et al., 1975.

USER INPUTS

(ACFM) = Effluent gas flow rate
(E) = SO_2 emission rate tons/day
(Days) = Annual days of operation
*($/KWH) = Electric power
*($/m gal) = Raw water
*($/mmBTU) = Reheat (for utility applications)
*($/ton) = Lime (CaO)
*($/ton) = Soda ash ($Na_2CO_3$)
($/hr) = Labor rate
($/ton) = Cost of disposal of sludge solids
(i) = Interest rate

5. Wellman-Lord Process. (SO_2 recovery 90%)

Since the maximum sized unit is 350,000 ACFM, two (2) units will be used, each having the following characteristics (ACFM) = 298,427 and (E) = 496.6 tons/day.

$$\text{Capital Cost (C.I.)} = 1800(\text{ACFM})^{.60} + 250{,}000(\text{E})^{.65}$$

$$= \$3.474 \text{ million} + \$13.275 \text{ million}$$

$$= \$16.749 \text{ million/unit}$$

$$\text{Total CI} = \$33{,}498 \text{ million}$$

$$\text{annual operating cost} = \left(\frac{(\text{ACFM})}{1000}\right)(\text{Days})\left[300\ (\$/\text{KWH}) + 1.5\ (\$/\text{mmBTU})\right]$$

$$+ (\text{E})(\text{Days})\Big[166.3\ (\$/\text{KWH}) + 9.22\ (\$/\text{m lb steam}) + 0.8(\$/\text{m gal } H_2O)$$

$$+ 6.37\ (\$/\text{m CF methane}) + 71.25(\$/\text{lb } Na_2CO_3)\Big]$$

$$+ 26{,}280\ (\$/\text{hr}) + 0.06(\text{C.I.}) + 0.025(\text{C.I.})$$

($/KWH)= $.015/KWH ($/MCFCH_4) = $1.25/MCF*
($/mmBTU) = $1.25/mmBTU ($/lb $NaCO_3$) = $.025/#$NaCO_3$
($/m#steam) = $1.25/m#steam
($/m gal H_2O) = $.10/m gal

*From Appendix II, Bellagia, et al., 1975.

assume: (\$/hr) = \$8/m

(Days) = 365

annual operating cost $= \frac{(298,427)}{1000}(365)\left[300(0.015) + 1.5\ (1.25)\right]$

$+ 496.6\ (365)\ \left[166.3\ (0.015) + 9.22\ (1.25)\right.$

$\left. + .8\ (.10) + 6.37\ (1.25) + 71.25\ (.025)\right]$

$+ 26,280\ (8) + .06\ (16.749 \times 10^6) + .025\ (16.749 \times 10^6)$

= \$6.648 million/yr-unit

6. Citrate Process. (SO_2 recovery 95%)

For this process the maximum sized system is 350,000 ACFM. Subsequently two (2) units will be needed. Each unit will have an (ACFM) = 298.427 and (E)= 496.6tons/day.

Capital Cost (C.I.) $= 1800(\text{ACFM})^{.60} + 220,000(E)^{.60}$

= \$3.474 Million + \$9.064 million

= \$12.538 million/unit

Total CI = \$25.076 million

annual operating costs $= \frac{(\text{ACFM})}{1000}$ (Days) $\left[300(\$/\text{KWH}) + 1.5\ (\$/\text{mmBTU})\right]$

$+$ (E) (Days) $\left[190(\$/\text{KWH}) + 1.71(\$/\text{m gal } H_2O)\right.$

+ 3.8 (\$/m lb steam)

+ 6.37(\$/m CF methane) + 4.28(\$/lb citric acid)

$\left. + 29.2\ (\$/\text{lb } Na_2CO_3)\right]$

+ 26,280 (\$/hr) + 0.06(C.I.) + 0.025(C.I.)

(\$/KWH) = \$0.015/KWH*

(\$/mmBTU) = \$1.25/mmBTU

(\$/m gal H_2O) = \$.10/m gal H_2O

(\$/m# steam) = \$1.25/m#

(\$/MCFCH_4) = \$1.25/MCRCH_4

(\$/#citric acid) = \$.425/#

(\$/#NA_2CO_3) = \$.025/#$NACO_3$

*From Appendix II, Bellagia, et al., 1975.

assume: (\$/hr) = \$8/hr

(Days) = 365

annual operating costs

$$= \frac{(298{,}427)}{1000} (365) \left[300\ (0.015) + 1.5\ (1.25)\right] + 496.6\ (365) \left[190\ (0.015) + 1.71 + 3.8(1.25) + 6.37(1.25) + 4.28\ (.425) + 29.12\ (.025)\right] + 26{,}280(8) + .06\ (12.538 \times 10^6) + 0.25\ (12.538 \times 10^6)$$

$$= \$5.28387 \text{ million/yr-unit}$$

OPERATING DATA INPUT

Power: Scrubbing 0.30 KWH/ACFM-day

Sulfur Handling 400 KWH/ton sulfur

Reheat: 0.0015mm BTU/ACFM-day (utility applications only)

Process Water: 3.6m gal/ton sulfur

Steam: 8m lb/ton sulfur

Methane: 13.4m CF/ton sulfur

Citric Acid: 9 lb/ton sulfur

Soda Ash: 61.5 lb/ton sulfur

Labor: Fixed at 2½ men/shift (with 20% allowance for fringes and benefits

Maintenance: 0.06 C.I.

Capital Charges: 15-year life

Taxes, insurance, etc. 2.5% C.I.

USER INPUTS

(ACFM) = Effluent gas flow rate

(E) = SO_2 emission rate-tons/day

(Days) = Annual days of operation

(\$/KWH) = Electric power

(\$/mm BTU) = Reheat (for utility applications)

(\$/m gal) = Process water

(\$/m lb) = Steam

(\$/lb) = Citric acid

(\$/lb) = Soda ash (Na_2CO_3)

(\$/hr) = Labor rate

(\$/ton) = Credit or debit for elemental sulfur disposal

(i) = Interest rate

7. Total Suspended Particulates.

The total amount of TSP to be removed from the St. Louis Area is 44,000 tons/year during 1985 above and beyond emission reductions needed to attain the Air Quality Standard. To carry out the cost effectiveness analysis, a hypothetical uncontrolled coal burning power plant will be fitted with electro-static precipitations whose control efficiency is 90% to remove 44,000 tons/yr of TSP. The total emission rate from the furnaces would be 48,888 tons/year. If bituminous coal with 7% ash is used, the annual coal consumption will be 873,000 tons/year or 1.66 tons/min. Stoichemetric calculations utilizing 10% excess air and an ultimate analysis of the coal of 68.4% carbon, 5.6% hydrogen, 16.4% oxygen, 1.2% sulfur and 1.4% nitrogen with an exit exhaust temperature of 400°F yields an exhaust flow rate of 723,029 ACFM.

Capital Cost equation for an electro static precipitator is:

Capital Cost (\$1000) = 170 + 3.250 $(\text{ACFM}-10^3)$

Since (ACFM) = 723,029, the capital cost can be computed to be:

Capital Cost (\$1000) = 170 + 3.25 (723.029)

= \$2,519.840 or \$2.519 million

annual operating cost for the electrostatic precipitator can be calculated by:

$$\text{annual operating cost (AOC)} = (\text{ACFM})(\$/\text{KWH})(\text{Hrs})\left[(0.1955 \times 10^{-3})(0.5) + K\right] + (E)(n)(\text{Days})(\$2/\text{ton}) + (M)(C.1) + (L)(\text{Days})(\$/\text{hr}) + (0.025)(C.1)$$

USER INPUT

(ACFM) = Effluent gas flow rate to ESP

(Hrs) = Annual hours of operation

(\$/KWH) = Electric power

(\$/hr) = Labor rate

(K) = Constant. Dependent on level of ESP efficiency selected (Hi. = 0.0004; Med. = 0.0003; Lo = 0.0002)

(E) = Particulate emission rate (tons/day)

(n) = Efficiency

(M) = Maintenance constant 0.04 high efficiency
0.02 standard

(Days) = Annual days of operation

(L) = Operating labor factor (hours/day) < 100,000 ACFM = 2
> 100,000 ACFM = 4

($/KWH) = $0.015/KWH*

assume:
(HRS) = 365 x 24 = 8,760 hrs
($/hr) = $8/m
(Days) = 365
(n) = 90%

$$\text{annual operating cost} = 723{,}029\ (0.015)(8.760)\left[(.1955 \times 10^{-3})(.5) + 4 \times 10^{-4})\right]$$

$$+\ 134\ (.90)(365)(\$2) + (.04)(2.519 \times 10^{6}) + 4(365)\ (8)$$

$$+\ 0.25(2.519 \times 10^{6})$$

$$= \$310{,}733/\text{yr.}$$

*From Appendix II, Bellagia, et al., 1975.

APPENDIX B

REVIEW OF COMSIS CORPORATION'S "SINK" FACTOR INFORMATION CONTAINED IN VOLUME I OF OPEN SPACE AS AN AIR RESOURCE MANAGEMENT MEASURE

A. PROJECT OFFICER'S INTRODUCTION

The Environmental Protection Agency's Environmental Research Laboratory at Corvallis, Oregon was asked to review Volume I of the Open Space series of reports by the Land Use Planning Office of the Strategies and Air Standards Division. Dr. Lawrence C. Raniere of Corvallis's Terrestrial Ecology Branch asked Dr. Ernest W. Peterson, Research Meteorologist on assignment to the Branch from the National Oceanic and Atmospheric Administration, to review the Volume. Dr. Peterson's comments follow in Section B of this Appendix. He only addresses sulfur dioxide sink factors in Volume I, and not those presented for the other nine pollutants investigated (ammonia, carbon monoxide, chlorine, fluorine, hydrocarbons, nitrogen oxides, ozone, peroxyacetylnitrate (PAN), and particulates).

The authors of the Volume II material under discussion, Dr. Robert S. DeSanto of De Leuw, Cather & Company (formerly with COMSIS Corporation) and Dr. William H. Smith of Yale University's School of Forestry and Environmental Studies, were asked to respond to Dr. Peterson's comments. Their response, authored by Dr. DeSanto and concurred with by Dr. Smith, appears as Section C of this Appendix.

B. REVIEW OF "SINK" FACTORS BY DR. ERNEST W. PETERSON*

1. SO_2 Uptake (Flux) Rates

In order to determine the rate of uptake of pollutants by plant, soil, and water surfaces it is necessary to know the atmospheric conditions, such as wind, turbulence, temperature, humidity and pollutant concentration; in addition the state of the surface must be known, as well as its geometry, including the amount of surface area relative to ground area. Very little of the above information is known for any given situation, since there are usually severe technical and economic constraints on what can be known; thus one must be satisfied to make estimates with insufficient information if estimates are to be made at all.

---

*This material was originally entitled: "Estimates of Deposition Velocities for Sulfur Dioxide and an Analysis of the COMSIS Data Collection (1976) in Terms of Its Value for the Estimation of the Uptake of Sulfur Dioxide by Plant, Soil and Water Surfaces."

The simple relationship between the uptake rate and the ambient pollutant concentration can be given by the following equation:

$$F = v X,$$

where F is the flux or uptake rate of pollutant into and retained by the surface, X is the concentration of pollutant in the surrounding air, and v, which has the dimensions of velocity, is the proportionality constant between concentration and flux. v is frequently called the deposition veolcity and is presumed to be a parameter which is a function usually only of the surface and whether or not it is wet or dry. This equation is only a crude model of the actual process but may prove useful if a catalog of values for v for various surfaces can be obtained.

A perusal of some of the information* available on sulfur dioxide deposition yields the following bounds:

Maximum concentration of SO_2 in the atmosphere is $<8 \frac{mg}{m^3}$ (3 ppm)

Maximum deposition velocity is $\sim 30 \frac{cm}{sec}$ (This is independent of pollutant gas, based on elementary atmospheric boundary layer theory.)

Deposition velocity for SO_2 is $\sim 0.1 - 20 \frac{cm}{sec}$ (See Figure 1.)

Since these bounds have been fairly well established we expect that data on sulfur dioxide flux should be consistent with them.

---

*See attached references.

2. Review of COMSIS Data

The COMSIS (1976), data collection of "sink factors" (actually fluxes) was obtained from a large variety of sources. The data were presented, largely without comment, in terms of the type of surface and removal of uptake rate by that surface. A summary presenting characteristic removal rates was presented at the end of the data collection. Since the flux or removal rate is proportional to concentration, knowledge of the flux alone on some given occasion does not allow one to estimate the flux for a different situation when the concentration would most likely be different. Only if the deposition velocity is known can one estimate the flux for any situation given the concentration. The COMSIS data contain very little information on deposition velocities and are, therefore, of little use for estimating fluxes under conditions differing from those under which the data were taken. Nevertheless it is useful to know whether the data presented is consistent with what is known and expected about SO_2 uptake.

Table 1 contains a list of the COMSIS SO_2 data which were presented in terms of mass per unit time per unit ground area (flux). Also included are some data which are given in flux per unit concentration. The data are grouped in order of their quality as assessed by COMSIS. Where possible deposition velocities were taken or calculated from the given data; otherwise deposition velocities were calculated from the given fluxes and assumed (but possible) concentrations, and concentrations were calculated from assumed deposition velocities which were estimated for the particular surface. In this way it was determined whether or not the COMSIS fluxes were consistent with the bounds stated above. The flux data are all from the COMSIS report. Those others marked "given" are also from the report while those marked "derived" are derived directly from the COMSIS data. The comments in the column marked "COMSIS reference" refer to the COMSIS report.

Table 2 gives the conclusions from the analysis of each of the COMSIS data. Based on these conclusions a new data collection was compiled (Table 3). These data are consistent with the range of fluxes, deposition velocities, and concentrations found in the atmosphere. The concentrations at which the fluxes were measured were estimated to be high or low values of the concentrations found

TABLE 1

ANALYSIS OF COMSIS SO DATA COLLECTION

Surface Identification Number	Flux(1) F ($\mu g\ m^{-2}\ hr^{-1}$)	Concentration(2) X ($mg\ m^{-3}$)	Deposition Velocity(3) V ($cm\ sec^{-1}$)	Deposition Velocity(2) V ($cm\ sec^{-1}$)	Concentration(3) X ($mg\ m^{-3}$)	Comsis Quality Index	Comsis Reference Number
1. Alfalfa	21.38×10^5	3	20	2.8	20	1	88,523
2. Mustard	669.6			0.74(5)	0.03	2	169
3. Alfalfa	2900(4)		3.1 (6)			2	1970
4. Loblolly Pine	700(4)		0.74(6)			2	1970 (Winter)
5. Loblolly Pine	980(4)		1.0 (6)			2	1970 (Summer)
6. Rhodendron	81×10^2	3	0.08	1	0.2	2	1972
7. Firethorn	128×10^2	3	0.1	1	0.4	2	1972
8. Oolithic Limestone	168×10^3	0.37(5)	10			2	955
9. Various Soils			0.4-0.6(5)			2	1254*
10. Acid Soil	11520×10^3	3	100	0.2	2000	2	56 (H_2S)
11. Lake	325	3	0.003	0.5	0.02	2	1184 (SO_4)
12. Alfalfa	8202.9×10^3	3	80	2.8	80	3	64
13. Alfalfa	3.649×10^3	3	0.03	2.8	0.04	3	1413
14. Alfalfa	144.96×10^3	3	1	2.8	1	3	86
15. Forest	3.33×10^3	3	0.03	20	0.005	3	64
16. Vegetation	145.37×10^3	1.5(5)	3	1	4	3	523
17. Soil	4498	0.3	0.4	0.2	0.6	3	370
COMSIS SELECTED AVERAGES							
Vegetation	500	3	0.005	1	0.01		
Soil	11500×10^3	3	100	0.2	2000		
Water	300 SO_4	3	0,003	0.5	0.02		

Footnotes:
1. As presented in COMSIS Volume I.
2. Assumed unless otherwise noted.
3. Calculated unless otherwise noted.
4. In units of: per parts per hundred million (pphm).
5. Given.
6. Derived.

* Units error.

TABLE 2

ANALYSIS OF COMSIS DATA COLLECTION

IDENT. NO.	
1.	For reasonable settling velocity (2.8 cm/sec, Hill, 1971), calculated concentration too high to be believed; therefore given flux higher than expected for atmosphere.
2.	With given data calculated concentration just above background; flux lower than would be expected in polluted area.
3.	Data corroborates Hill. See (1).
4.	Deposition velocities seem low but not unbelievably so.
5.	Ditto.
6.	Appears to be flux in non-polluted area.
7.	Ditto.
8.	Deposition velocity from data appears to be more than an order of magnitude too high.
9.	Appears reasonable--units error in Comsis report.
10.	Flux is ridiculously high (H_2S flux).
11.	SO_4^{2-} flux.
12.	Flux too high.
13.	Seems to be nonpolluted area.
14.	Reasonable flux.
15.	Seems to be nonpolluted area.
16.	Deposition velocity calculated from data a bit high but not unbelievably so.
17.	Appears reasonable.

TABLE 2

ANALYSIS OF COMSIS DATA COLLECTION CONTINUED

ANALYSIS OF COMSIS SUMMARY FOR SO_2.

Vegetation - flux seems about right for background levels of SO_2.

Soil - this flux is based on one report of observations of H_2S flux over acid soil. It is several orders of magnitude too high.

Water - this flux of SO_4^{2-} is taken from some observations over a lake. It is about right for background levels of SO_2.

TABLE 3

SCREENED COMSIS DATA

Ident. No.	Surface	Flux ($\mu g\ m^{-2}\ hr^{-1}$)	Deposition Velocity ($cm\ sec^{-1}$)	Concentration ($\mu g\ m^{-3}$)
2.	Mustard	0.67×10^3	0.74(1)	25
3.	Alfalfa		3.1 (2)	
4.	Loblolly Pine		0.74(2)	
5.	Loblolly Pine		1.0 (2)	
6.	Rhododendron	8.1×10^3		Probably Low
7.	Firethorn	13×10^3		Probably Low
9.	Various soils		0.4-0.6	
13.	Alfalfa	3.6×10^3		Probably Low
14.	Alfalfa	140×10^3		Probably High
15.	Forest	3.3×10^3		Probably Low
16.	Vegetation	150×10^3		1.5
17.	Soil	4.5×10^3		Probably Moderately Low

Footnotes: (1)Given.
(2)Derived.

in the atmosphere consistent with a reasonable deposition velocity. The COMSIS summary of the flux of SO_2 to the soil presents a quantity which gives a completely unrealistic value of both the deposition velocity and concentration which would have to prevail for the reported flux to have occurred. One must conclude that either the datum is wrong or that it was measured in conditions not found in the atmosphere. The average fluxes to water and vegetation are appropriate for fluxes at low but above background levels of concentration.

Table 4 allows a comparison to be made between the global average emission rate of pollutants as estimated by Rasmussen, Taheri, and Kabel (1974) and projected global average removal rates based on the COMSIS (1976) summary of "sink factors". The emission and removal rates would agree if the Rasmussen and COMSIS data were representative of global emission and removal rates. Except in the case of hydrocarbons the COMSIS values are an order of magnitude higher than the Rasmussen values (for hydrocarbons they are two orders of magnitude smaller). At reasonable deposition velocities, at least for SO_2, these represent concentrations an order of magnitude higher than background but much lower than those that can be found in urban areas. Thus the COMSIS values are neither representative of global uptake rates nor maximum removal rates. Since COMSIS does not give deposition velocities or concentrations for which the reported fluxes are representative, these fluxes are not useful in estimating the uptake of pollutants by the earth's surface.

3. Conclusion

In conclusion, if one is to be able to make estimates of uptake of pollutants by plant, soil, and water surfaces, it is necessary at least to have knowledge of deposition velocities for various types of surfaces. Figure 1 is the result of an attempt at estimating these velocities. This figure is based on what information can be gleaned from the attached references and is only a first guess. However it is consistent with available data and probably yields estimates of deposition velocities to within an order of magnitude of their true values. For instance, the deposition velocity for a forest is probably around 10 cm/sec, for crops about 1 cm/sec, for water surfaces, about 0.5 cm/sec and for soil, about 0.2 cm/sec.

TABLE 4

COMPARISON OF GLOBALLY AVERAGED EMISSION AND ABSORPTION RATES FOR SULFUR DIOXIDE

Pollutant	Estimated Emissions by Rasmussen(1) ($\mu g\ m^{-2}\ sec^{-1}$)	Estimated Absorption from COMSIS Summary(2) ($\mu g\ m^{-2}\ sec^{-1}$)
SO_2	8×10^{-3}	100×10^{-3}
H_2S	6×10^{-3}	
NO_x	9×10^{-2}	60×10^{-2}
NH_3	1×10^{-2}	20×10^{-2}
CO	2×10^{-1}	20×10^{-1}
O_3		
HC	4×10^{-2}	0.04×10^{-2}

Footnotes: (1)Estimated global average.

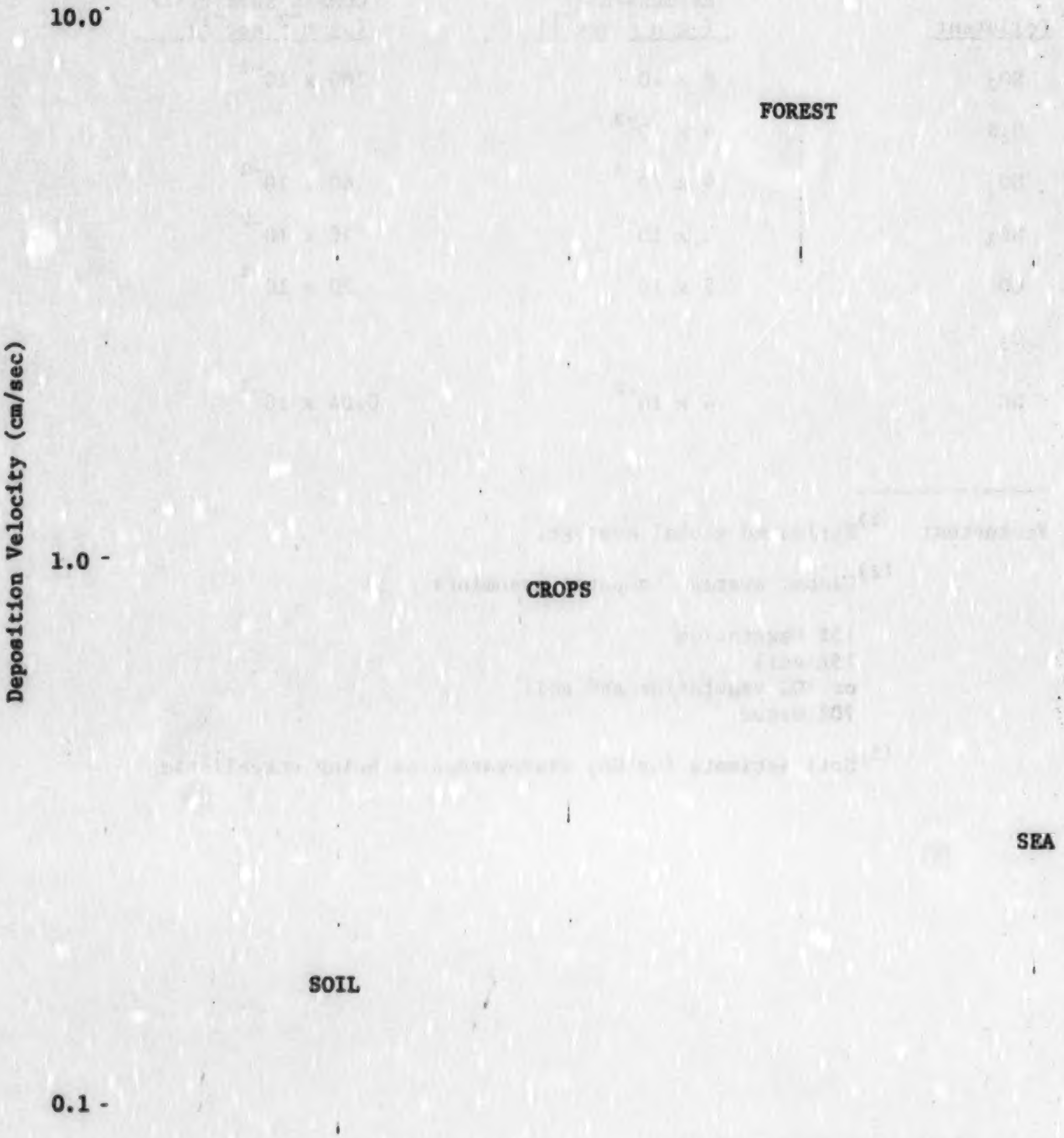
(2)Global average computed assuming:

15% vegetation
15% soil
or 30% vegetation and soil
70% water

(3)Soil estimate for SO_2 disregarded as being unrealistic

FIGURE 1

SULFUR DIOXIDE UPTAKE AT SURFACE OF EARTH
(Estimate)



Note: Deposition is Higher if Vegetation is Wet

4. References

Bennett, J. H. and A. C. Hill (1973): Absorption of gaseous air pollutants by a standardized plant canopy. *J. Air Poll. Contr. Assoc.*, *23*, 203.

Bennett, J. H. and A. C. Hill (1975): Interactions of air pollutants with canopies of vegetation. In *Responses of Plants to Air Pollution*, J. B. Mudd, editor, Academic Press, p. 273.

Bromfield, A. R. (1972): Absorption of atmospheric sulfur by mustard (Sinapsis alla) grown in a glass house. *J. Agric. Sci.*, *78*, 343.

COMSIS (1976): *Open Space as an Air Resource Management Measure, Vol. II Sink Factors*. Report to USEPA under Contract No. 68-02-2350; Robert S. DeSanto, Project Manager, COMSIS Corporation, Glastonbury, Connecticut. (Report contains an extensive bibliography, including abstracts of publications on deposition of air pollutants on soil, land and vegetation).

Dannevik, W. P., S. Frisella, L. Granat, and R. B. Husar (1976): In *Third Symposium on Atmospheric Turbulence, Diffusion*, and *Air Quality*, Amer. Meteor. Soc., p. 506.

Droppo, J. G., D. W. Glover, O. B. Abbey, C. W. Spicer, and J. Cooper (1976): *Measurement of Dry Deposition of Fossil Fuel Plant Pollutants*. Report to USEPA under Contract No. 68-02-1747. EPA-600/4-076-056.

Fowler, D. and M. H. Unsworth (1974): Dry deposition of sulfur dioxide on wheat. *Nature*, *249*, 389.

Garland, J. A. (1974): Dry deposition of SO_2 and other gases. In *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants*, NTIS No. CONF-740921, p. 212.

Garland, J. A., D. H. F. Atkins, C. J. Readings, and S. J. Caughey (1974): Deposition of gaseous sulfur dioxide to the ground. *Atmos. Environ.* *8*, 75.

Hicks, B. B. (1974): Some micrometeorological aspects of pollutant deposition rates near the surface. In *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants*, NTIS No. CONF-740921, p. 434.

Hill, C. H. (1971): Vegetation: a sink for atmospheric pollutants. *J. Air Poll. Cont. Assoc.*, *21*, 341.

Kabel, R. J., R. A. O'Dell, M. Taheri, and D. D. Davis (1976): *A Preliminary Model of Gaseous Pollutant Uptake by Vegetation*. CAES Pub. No. 455-76, Center for Air Environment Studies, University Park, Pennsylvania.

Liss, P. S. and P. G. Slater (1974): Flux of gases across the air-sea interface. *Nature*, *247*, 181.

Liss P. S. and P. G. Slater (1974): Mechanism and rate of gas transfer across the air-sea interface. In *Atmospheric-Surface Exchange of Particulate and Gaseous Pollutants*, NTIS No. CONF-740921, p. 354.

Martin, A. and F. R. Barber (1971): Some measurements of loss of atmospheric sulfur dioxide near foliage. Atmos. Environ., 5, 345.

Murphy, B. D. (1976): Description of SO_2 on ground cover. In Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, Amer. Meteor. Soc. p. 500.

National Air Pollution Control Administration (1969): Air Quality Criteria for Sulfur Oxides. NAPCA Pub. NO. AP-50.

Owers, M. J. and A. Q. Powell (1974): Deposition velocity of sulfur dioxide on land and water surfaces using a ^{35}S tracer method. Atmos. Environ., 8, 63.

Rasmussen, K. H., M. Taheri, and R. L. Kabel (1975): Global emissions and natural processes for removal of gaseous pollutants. Water, Air, and Soil Pollution, 4, 33.

Saito, T. (1974): Absorption of sulfur dioxide in leaves as affected by light and wind. J. Japan, Soc. Air Poll., 9, 1.

Shepard, J. G. (1974): Measurements of the direct deposition of sulfur dioxide onto grass and water by the profile method. Atmos. Environ., 8, 69.

Spedding, D. J. (1972): Sulfur dioxide absorption by sea water. Atmos. Environ., 6, 583.

Terraglio, F. P. and R. M. Mangelli (1966): The influence of moisture on the adsorption of atmospheric sulfur dioxide by soil. Int. J. Air and Water Poll., 10, 783.

Terraglio, F. P. and R. M. Manganelli (1967): The absorption of atmospheric sulfur dioxide by water solutions. J. Air Poll. Cont. Assoc., 19, 403.

Unsworth, M. H. and D. Fowler (1974): Field measurements of sulfur dioxide fluxes to wheat. In Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants, NTIS No. CONF-740921, p. 342.

C. RESPONSE TO THE REVIEW BY DR. ROBERT S. DeSANTO AND DR. WILLIAM H. SMITH*

1. In his review of the COMSIS data (starting on p. IX-3), Dr. Peterson observes that the Comsis data is "of little use for estimating fluxes under conditions differing from those under which the data were taken." This was a constraint on the study, is so identified, and is a result of the empirical data selected and weighted in order to represent what we felt was a representation of conditions likely to be approached in the design principles outlined in Volume II of the open space study.

2. In his discussion of Table 1 of his review (p. IX-3), Dr. Peterson indicates that either deposition velocities were calculated from the Comsis data, or from given fluxes and "...assumed (but possible) concentrations..." The Comsis data is an emperical report based entirely upon the literature with no extrapolation whatsoever associated with the data.

3. In Table 1, Dr. Peterson notes that there is a "units error" for the Various Soils category (Identification #9; see p. IX-4 .) The error referred to involves our Reference #1254, listed on p. V-126 of Volume I. The reference is: M. Payrissat and S. Beilke, "Laboratory Measurement of the Uptake of Sulfur Dioxide by Different Soils," Atmospheric Environ, 9: 211-217 (February 1975). We have double-checked this reference and the units are not in error. Perhaps Dr. Peterson may be concerned with the "order" of units. He has a point there. Some of the units should be altered; e.g., for Rendsina soil the units should be changed from .60 SO_2 cm 3200 cm^{-2} sec^{-1} to .60 SO_2 cm sec^{-1} 3200 cm^{-2}.

4. In Dr. Peterson's discussion of his Table 2 (p. IX-3), he states that the SO_2 flux to soil is "...completely unrealistic...". As in all other instances, the reported data is taken from the published, reputable, and professional literature. To the best of our knowledge and belief, that data is completely real and reliable. From that literature, it is clear that soil is an excellent sink for SO_2. The design guidelines in Volume II are largely aimed at bringing the turbulent atmosphere into contact with the soil.

---

*The response was originally contained in a letter to the Project Officer, Thomas McCurdy, from Dr. Robert S. DeSanto, dated April 6, 1977. Attached to it was a letter from Dr. William H. Smith to Dr. DeSanto, dated March 31, 1977.

5. Table 2 lists notes associated with the calculated or assumed fluxes which, therefore, are apparently Dr. Peterson's comments on the literature. In some instances (surface identification numbers 1, 2, 8, 10, and 12), Dr. Peterson disputes the validity of the literature. We believe the literature is correct.

In general, this table seems to contradict Dr. Peterson's own review comments relative to the alledged unreality of the literature.

6. Of particular interest, Table 4 compares the literature presented by Comsis (which considered the Rasmussen data cited by Dr. Peterson) with emissions derived from Rasmussen. We see no illogic or contradiction between the literature which the Comsis report compiled and the Rasmussen estimates. For example, Comsis reported from the literature that SO_2 could be absorbed by the earth at a rate of 100 units. Rasmussen reports an estimate of emissions rate of 8 units. If both estimates are correct, we should be able to conclude that SO_2 is not a worldwide problem even though it may be a regional problem. In the same way, CO is estimated by the Comsis literature to be absorbed at a rate of 20 units while the Rasmussen estimate of emissions is 2 units. Therefore, we should conclude that CO is not a worldwide problem, nor does it threaten to become one. In an opposite direction, the Comsis literature is presented which indicates that HC is absorbed by the earth at the rate of 0.04 units while Rasmussen reports an estimated emission rate of 4 units. This would suggest that HC emissions are a worldwide problem of some as of yet undetermined magnitude.

The same types of conclusions apply to the other values in Table 4. Our conclusion is that the Comsis literature is in agreement with the use of the Rasmussen data reported by Dr. Peterson.

7. In summary, Comsis's report of the literature in Volume I did not involve new experimentation or extrapolation of pre-existing data. It reported the literature in an order and format which Comsis felt most responsive to the contract charge of reviewing the material. Dr. Peterson's technical note raises questions which seems to be directed at the accuracy of data reported in the literature, rather than the organization and presentation of that literature by Comsis itself.

APPENDIX C

CORRECTIONS TO THE GAUSSIAN DIFFUSION EQUATION MATERIAL IN VOLUME II OF OPEN SPACE AS AN AIR RESOURCE MANAGEMENT MEASURE

A. PROJECT OFFICER'S INTRODUCTION

The Land Use Planning Office of the Strategies and Air Standards Division asked a number of EPA groups to review Volumes I and II of the final report for the Open Space project. Mr. James L. Dicke, Supervisory Meteorologist on assignment to the Source-Receptor Analysis Branch, Monitoring Data and Analysis Division, from the National Oceanic and Atmospheric Administration, returned a number of comments that clarify material appearing in Volume II of *Open Space as an Air Resource Management Measure*. The material involves the Gaussian diffusion model presented in Section II.A.3., "Atmospheric Diffusion (p. II-10ff). Mr. Dicke's comments are keyed to specific parts of the material.

B. CORRECTIONS TO THE MATERIAL BY JAMES L. DICKE

1. On page II-11, Figure II-4 and Equation (1) apply only to continuous *point* sources. The asterisk after "exp" is not defined; the equation means that e, the natural log, is raised to the exponent indicated by the brackets.

On page II-12, the assumptions should include the fact that "emissions are from a continuously emitting point source."

2. Comsis uses the symbol μ or $\bar{\mu}$ for mean wind speed. This may cause confusion with "micro," as in particle size, usually depicted by that symbol. Normally, u is used for mean wind speed.

On p. II-12 Comsis defines mean wind speed in units of $g\ sec^{-1}$, but it should be $m\ sec^{-1}$. This is probably a typographical error, as the correct units appear on p. II-13. Also in the definition of units, x ($g\ m^{-3}$) should be χ, the Greek chi.

3. Equation (2) applies to *elevated point sources* and ground-level concentrations calculated at any *cross-wind distance y*.

4. Equation (3) applies to elevated point sources and ground-level concentrations along the center line of the plume.

5. Comsis references Turner (1972) in a number of places on p. II-13. This citation is to D. B. Turner and J. L. Dicke, "Atmospheric Diffusion Computations," p. 3.19 - 3.46 in EPA, Air Pollution Meteorology (Research Triangle Park, N. C., 1972). This publication is a training manual and it is EPA policy not to officially approve training manuals for quotation or citation. The COMSIS reference should be to the original source, which is: D. Bruce Turner, Workbook of Atmospheric Dispersion Estimates (Research Triangle Park, N.C., 1970; AP-26).

6. Equation (6) on p. II-16 has a number of typographical errors in it. Q is defined correctly in the lead-in paragraph, but incorrectly in the list of variables below the equation. Q is the estimate of source emissions in g m^{-1} sec^{-1}, not an estimate of pollutant concentration in g m^{-3}. Equation (6) has another typo in the 10.7 term inside the doubled parentheses. It should be: 10^{-7} (power). The constant term, then, in more conventional notation is 1.73×10^{-7} (actually 1.7264×10^{-7}).

7. The refernece for equation (6) on p. II-16 is incorrect, although it is cited correctly in the bibliography. The correct title for the citation is Supplement No. 5 for Compilation of Air Pollution Emission Factors.

8. Equation (8) on p. II-16 again presents scientific notation in an unusual way. The constant term in the equation is 1.51×10^{-4}.

9. The Holland plume rise equation on p. VI-53 contains a number of errors. For one, there is a symbol "H=" but nothing follows; it should be removed. On the next line, parentheses should be used to set off the term: $1.5 + 2.68 \times 10^{-3} \cdot \Delta T \cdot d \cdot p^{-1} \cdot T_s^{-1}$.

In the definition of units, ΔT should be defined as: stack gas temperature - ambient air temperature (^{O}K). The constant term beneath ΔT stands alone, and is correct.